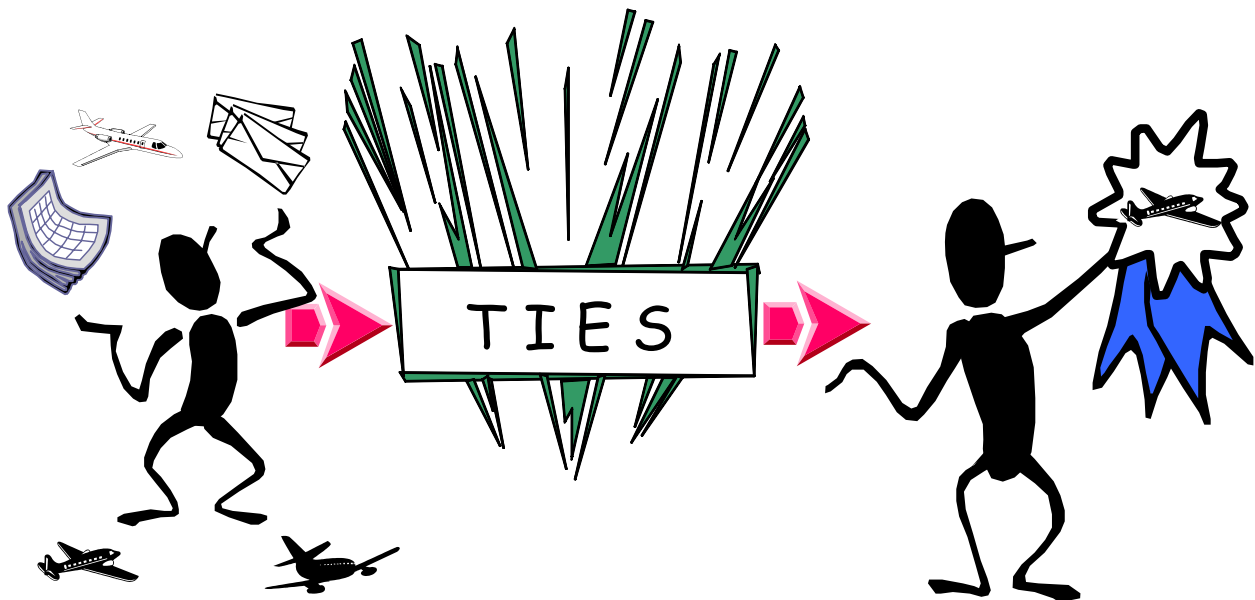


TIES for Dummies

3rd Edition

(Technology Identification, Evaluation, and Selection)

Basic how to's to implement the TIES method



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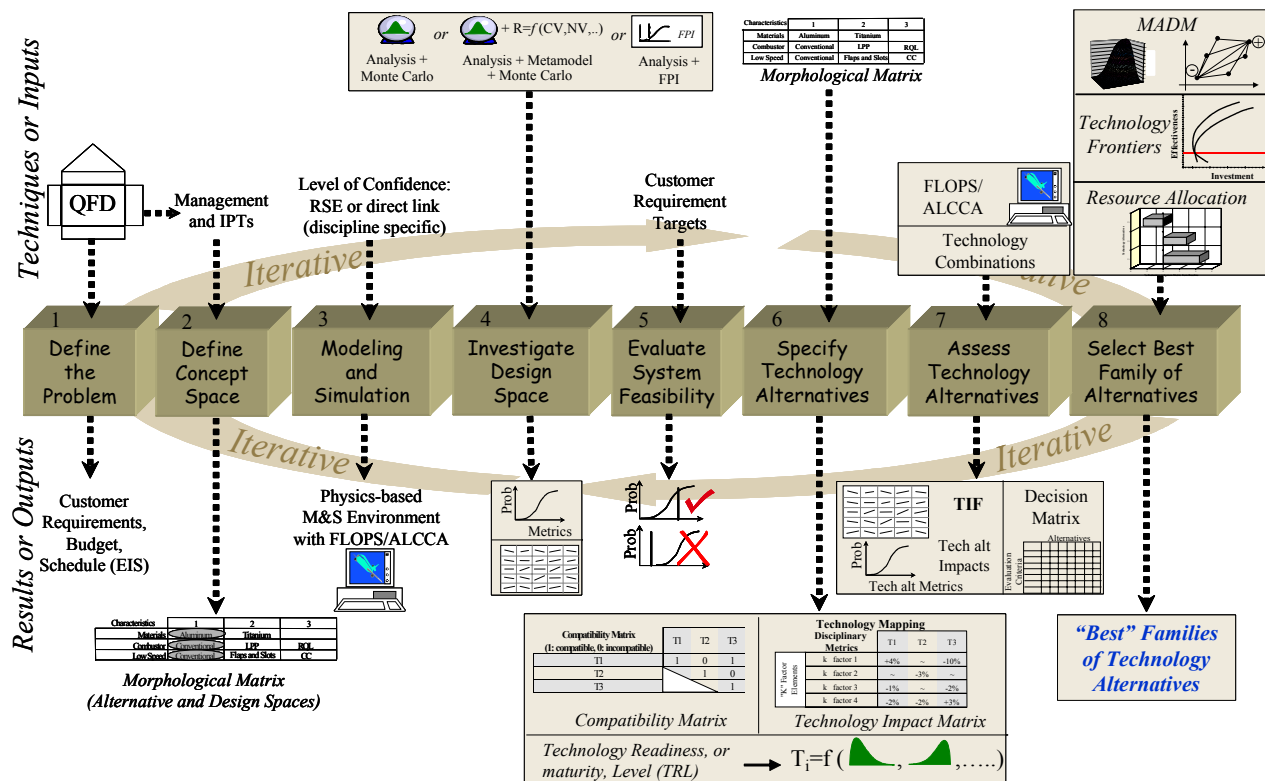
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TIES for Dummies

The TIES method is a forecasting environment whereby the decision-maker has the ability to easily assess and trade-off the impact of various technologies without sophisticated and time-consuming mathematical formulations. TIES provides a methodical approach where technically feasible alternatives can be identified with accuracy and speed to reduce design cycle time, and subsequently, life cycle costs, and was achieved through the use of various probabilistic methods, such as Response Surface Methodology and Monte Carlo Simulations. Furthermore, structured and systematic techniques are utilized from other fields to identify possible concepts and evaluation criteria by which comparisons can be made. This objective is achieved by employing the use of Morphological Matrices and Multi-Attribute Decision Making techniques. Through the execution of each step, a family of design alternatives for a given set of customer requirements can be identified and assessed subjectively or objectively. This methodology allows for more information (knowledge) to be brought into the earlier phases of the design process and will have direct implications on the affordability of the system. The increased knowledge allows for optimum allocation of company resources and quantitative justification for program decisions. Finally, the TIES method provided novel results and quantitative justification to facilitate decision making in the early stages of design so as to produce affordable and quality products.

The steps of TIES:

1. Define the problem
2. Define Concept Space: design and technology concepts identification
3. Modeling and simulation
4. Investigate design space
5. Evaluate of system feasibility/viability: probability of success
6. Specify Technology Alternatives
7. Assess Technology Alternatives
8. Select Best Family of Alternatives



The following tutorial explains how to implement each of the steps from a computational or evaluation point of view. References associated with the TIES method are listed below and can be obtained from the web site: <http://www.asdl.gatech.edu/publications/index.html>.

1. Kirby, M.R., Mavris, D.N., "A Method for Technology Selection Based on Benefit, Available Schedule and Budget Resources", SAE 2000-01-5563.
2. Kirby, M.R., Mavris, D.N., "Forecasting Technology Uncertainty in Preliminary Aircraft Design", SAE Paper 1999-01-5631.
3. Mavris, D.N., Kirby, M.R., "Technology Identification, Evaluation, and Selection for Commercial Transport Aircraft", 58th Annual Conference Of Society of Allied Weight Engineers, San Jose, California 24-26 May, 1999.
4. Mavris, D.N., Kirby, M.R., Qiu, S., "Technology Impact Forecasting for a High Speed Civil Transport", World Aviation Congress and Exposition, Anaheim, CA, September 28-30, 1998. SAE-985547.
5. Mavris, D.N., Mantis, G., Kirby, M.R. "Demonstration of a Probabilistic Technique for the Determination of Economic Viability," World Aviation Congress and Exposition, Anaheim, CA, October 13-16, 1997. SAE-975585.

So, let's begin.

Step 1: Problem Definition

The first step in TIES is to define the problem in terms of the customer requirements for which the product will be designed, the available budget to expend on the development, and the time frame in which the product must enter the market. In order to formulate the problem, a customer or societal need must exist or a request for proposal must be stated to drive the design of a new product. This need is often termed the "voice of the customer" and is typically qualitative, or ambiguous, in nature. For example, a commercial airline performs a market study and identifies that a majority of potential passengers wish to have lower fares and more flight time options. These are subjective and qualitative "wants" that must be mapped into some economic, engineering, or mathematically quantifiable terminology. The result of this step is the identification of the system level metrics which capture the customer requirements and will be the measure of success of the system under consideration.

Table 1: Metrics and Constraints:

Parameter	Acronym	Target or Constraint	Units
<u>Performance</u>			
Approach Speed	Vapp	= 155	kts
FAR Stage II Flyover Noise	FON	= 106	EPNLdB
Landing Field Length	LdgFL	= 11,000	ft
FAR Stage II Sideline Noise	SLN	= 103	EPNLdB
Takeoff Field Length	TOFL	= 11,000	ft
Takeoff Gross Weight	TOGW	= 1,000,000	lbs
<u>Economics</u>			
Acquisition Price	Acq\$	<i>Minimize</i>	FY96 \$M
Research, Development, Testing, and Evaluation	RDT&E	<i>Minimize</i>	FY96 \$M
Average Required Yield per Revenue Passenger Mile	\$/RPM	= 0.10	FY96 \$M
Total Airplane Related Operating Costs	TAROC	<i>Minimize</i>	FY96 ¢
Direct Operating Costs plus Interest	DOC+I	<i>Minimize</i>	FY96 ¢

Step 2: Define Concept Space: Design and Technology Concepts

Once the customer requirements are defined in terms of quantifiable engineering parameters, the thrust of the TIES method begins with the definition of the concept space and is driven by innovation and “out-of-the-box” thinking. Initially, the experience, knowledge, and intuition of the designer is utilized to identify a potential class of vehicles and provides the methodology with a starting point for selecting potential solutions to satisfy the customer requirements. The focus of this step is two-fold: identify the space of alternative concepts that is based on a defined class of vehicles, and establish the geometric and propulsive design space for which system feasibility is initially sought.

Define Technology and Concept Space

In the design of any complex system, there exists a plethora of combinations of particular subsystems or system characteristics that may satisfy the problem at hand. For example, how many engines are needed? What is the cruise speed? What type of high lift system is needed? Is a horizontal stabilizer preferred over a canard? A functional and structured means of decomposing the system and identifying component options is through the use of a morphological analysis. The Morphological Matrix is formed by identifying the major functions or characteristics of a system on the vertical scale and all the possible alternatives for satisfying the characteristics on the horizontal scale. In essence, this is where the technology alternatives, both mature and immature, to be considered in later steps are defined. Once the matrix is populated, an alternative design concept is defined as a mix of the characteristic alternatives. All possible design alternative combinations define the alternative concept space. In general, one alternative concept is established to begin the feasibility investigation and will be called the baseline concept and is typically drawn from mature technologies. Please refer to references 3 and 4 for more info.

Table 2: Morphological Matrix for HSCT

Alternatives Characteristics		1	2	3	4
Config Mission	Vehicle	Wing & Tail	Wing & Canard	Wing, Tail & Canard	Wing
	Fuselage	Cylindrical	Area Ruled	Oval	
	Pilot Visibility	Synthetic Vision	Conventional	Conventional & Nose Droop	
	Range (nmi)	5000	6000	6500	
	Passengers	250	300	320	
	Mach Number	2	2.2	2.4	2.7
Propulsion	Type	MFTF	Turbine Bypass	Mid Tandem Fan	Flade
	Materials	Conventional	High T Comp		
	Combustor	Conventional	RQL	LPP	
	Nozzle	Conventional	Internal Flow Alteration	Mixed Ejector	Mixer Ejector & Acoustic Liner
Aero	Low Speed	Conventional Flaps	Conventional Flaps & Slots	C C	
	High Speed	Conventional	NLEFC	Active Control	HLEFC
Struct	Materials	Aluminum	Titanium	High Temp. Composite	
	Process	Integrally Stiffened	Spanwise Stiffened	Monocoque	Hybrid

Define the Design Space

Once the baseline concept is defined from the alternative concept space, the baseline may be further decomposed into product and process characteristics. This can be performed via the Morphological Matrix or through brainstorming sessions with IPTs. Primary product attributes include the physical design parameters that describe a characteristic of the system. In conceptual and preliminary aircraft design phase, all of the design parameters should not be fixed but should vary within some specified range until such time as a configuration is “frozen”. The process attributes include certification, manufacturing, economic, and operational parameters, which are inherently uncertain.

Within the context of TIES, the product attributes are the key design variables (with associated ranges) which define the design space of interest for a given alternative concept. These design variables are often referred to as “control” factors, or variables that are within the designer’s control. These key design variables, and associated ranges, define the design space in which system feasibility is sought. The design variable ranges are chosen such that the largest possible deviations in the given baseline configuration may be captured. This implies that the system must have a converged solution, that is, be capable of flying the specified mission. However, care should be taken so that a handful of variables do not artificially dominate the design space due to larger relative ranges. For example, if one variable is allowed to deviate $\pm 5\%$, other variable deviations should be the same order of magnitude.

Table 3: Design Variables and Ranges With Baseline Configuration.

Variable	Minimum	Maximum	Baseline Value	Units	Description
SW	7500	9000	900	ft ²	Wing Area
TWR	0.29	0.33	0.29	~	Thrust-to-weight ratio
TIT	3000	3400	3000	°R	Turbine Inlet Temperature
FPR	3.5	4.5	4.5	~	Fan Pressure Ratio
OPR	18	21	18	~	Overall Pressure Ratio
CL _{des}	0.08	0.12	0.1	~	Design Lift Coefficient
X2	1.54	1.69	1.609	~	LE kink x-location*
X3	2.1	2.36	2.36	~	LE tip x-location*
X4	2.4	2.58	2.58	~	TE tip x-location*
X5	2.19	2.37	2.19	~	TE kink x-location*
X6	2.18	2.5	2.18	~	TE root x-location*
Y2	0.44	0.58	0.51	~	LE kink y-location*
t/c root	3	5	4	%	Wing root thickness-to-chord ratio
t/c tip	2	4	3	%	Wing tip thickness-to-chord ratio
SH _{ref}	400	700	550	ft ²	Horizontal Tail Area
SV _{ref}	350	550	450	ft ²	Vertical Tail Area

*Variable normalized by wing semi-span

Step 3: Modeling and Simulation

A modeling and simulation (M&S) environment is needed to facilitate rapid assessments with minimal time and monetary expenditures of the alternative concepts identified in the Morphological Matrix. Most companies have an in-house developed M&S environment to perform the design trades. The TIES method is not code specific, but the M&S tool utilized must have some basic features as outlined in Table 4. One cannot underestimate the importance of having a cohesive M&S environment. Without this environment, application of the TIES method is arduous. A principle requirement for any decision making process is the ability to quantitatively assess the customer requirements that drive a design. This can only be achieved through an M&S environment. The requirements for the M&S environment in Table 4 are directed towards aircraft analysis codes. However, one may extrapolate the features needed for ANY system design code.

If the class of vehicle that you are considering falls in the validity range of the analysis tool, you are ready to go. Most of the existing public domain codes are based on historical data for evolutionary concepts. If the designs of interest fall within this range, the sizing and synthesis codes can accurately assess the objectives. Yet, for a revolutionary concept the validity of the results will be questionable. This inability can be overcome through direct linking of more physics-based analytical models, or using metamodels to represent the physics-based analysis tool. Look at reference 4 for more information.

Table 4: Required Features Needed for an M&S Environment

Feature	Importance	Purpose
Parametric inputs	<i>High</i>	To quantify outputs in terms of inputs and facilitate the use of Response Surface Methods
Physics based	<i>Medium High</i> (based on level of confidence desired)	To analyze and model evolutionary or revolutionary concepts
Synthesis capability	<i>Average</i> (could use table look-ups created off-line)	To quantify the various disciplines (aerodynamics, structure, and propulsion) for a given configuration
Unconstrained mission analysis	<i>Medium High</i>	To “size” the system in terms of a fuel and thrust balance to fulfill a given mission that results in a “sized” vehicle and corresponding weights in an unconstrained manner so as to employ the use of metamodels for a continuous design space
Robust input definition	<i>High</i>	To allow for a wide range of configurations or missions to be analyzed
Economic analysis	<i>High</i> (assumes economics are a key driver)	To immediately quantify the impact of design changes on the economic requirements of the system
Responses are quantifiable	<i>Medium High</i>	To functionally relate the responses of interest to the variations of inputs
Disciplinary technical metric impact factors	<i>Very High</i>	To simulate the discontinuity associated with the addition of new technologies
Automation capability	<i>Average</i>	To facilitate probabilistic design methods and to have a “wrapper” around the tool
Rapid Assessments	<i>Average</i>	To facilitate reduced cycle time
Access to source code	<i>Average</i>	To modify fidelity deficiencies of different disciplines as needed and understand internal control laws or to add technical metric “k” factors

Table 5: HSCT Baseline Metrics

Parameter	Acronym	Baseline Value
<u>Performance</u>		
Approach Speed	Vapp	154.1 kts
FAR Stage II Flyover Noise	FON	112.3 EPNLdB
Landing Field Length	LdgFL	9,063.2 ft
FAR Stage II Sideline Noise	SLN	111.6 EPNLdB
Takeoff Field Length	TOFL	12,407 ft
Takeoff Gross Weight	TOGW	937,108 lbs
<u>Economics</u>		
Acquisition Price	Acq\$	218.58 FY96 \$M
Research, Development, Testing, and Evaluation	RDT&E	16,124.9 FY96 \$M
Average Required Yield per Revenue Passenger Mile	\$/RPM	0.1236 FY96 \$
Total Airplane Related Operating Costs	TAROC	5.948 FY96 ¢
Direct Operating Costs plus Interest	DOC+I	5.058 FY96 ¢

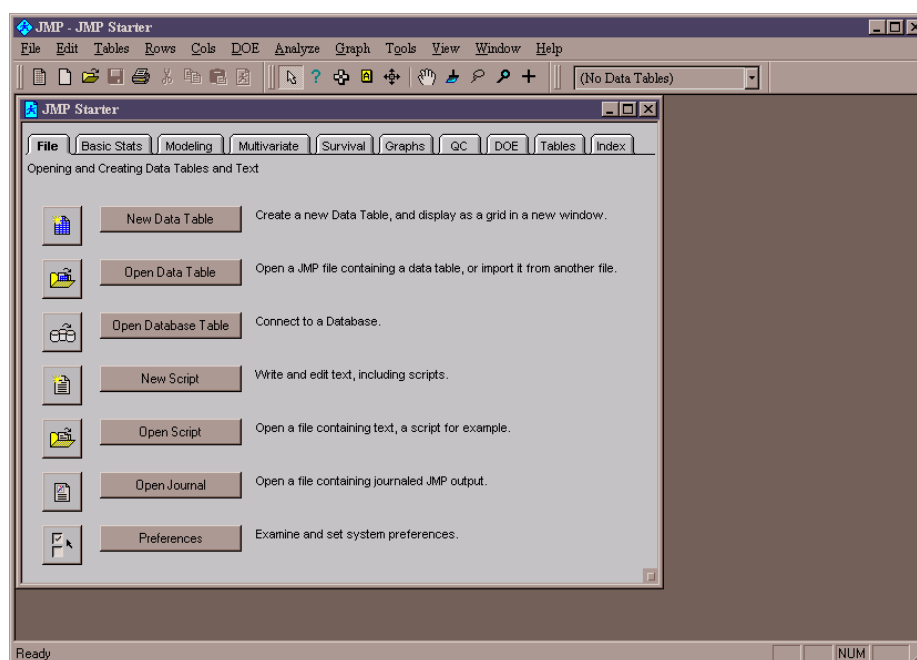
Step 4: Design Space Exploration

For the purpose of this tutorial, I will assume that you will use Response Surface Equations (i.e., a metamodel) representation of your metrics in conjunction with a Monte Carlo Simulation. In this step, you are trying to determine the metric values for any combination of design variables, i.e., where the metrics are as a function of design variables relative to the target values you identified in Step 1. The first step is to create a Design of Experiments (DoE) table. DoE is a technique to study the interactions between the design variables and their effects on the response metrics. Full factorial DoEs can only handle up to 16 variables, because the number of cases to run increases exponentially with more variables. For example, if you had 12 variables with two possible settings or levels, you would have 4096 or 2^{12} combinations to investigate. This is why it is important to use a fractional factorial DoE or to perform a screening test to eliminate some of the non-contributing variables. DoEs for more than 16 variables do not exist. Based on the Pareto Principle, it is rare that more than a handful of variables actually contribute to the response of interest. You can do a screening test at anytime, no matter how many variables you have. So, let's perform a screening test.

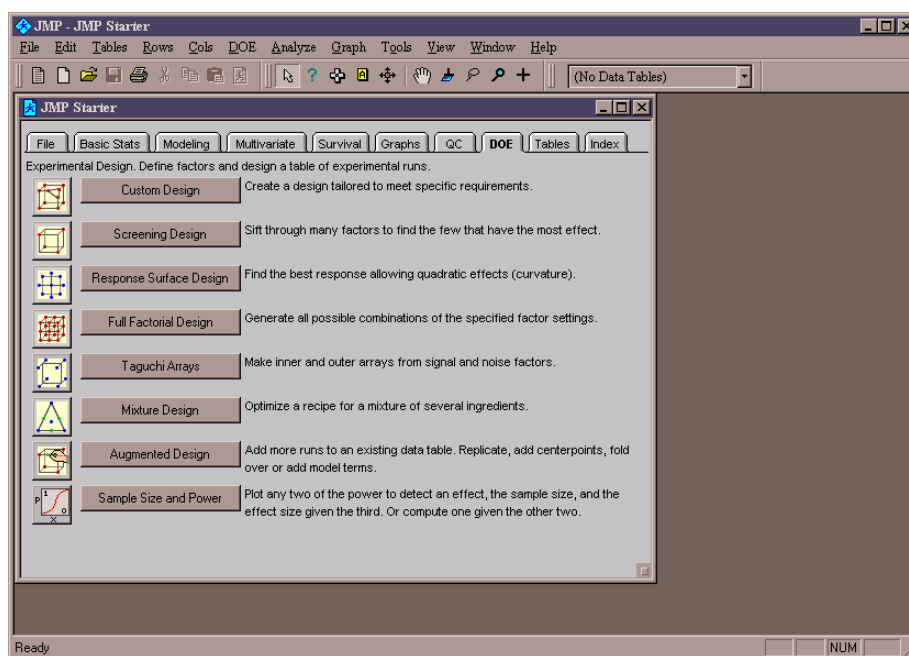
Screening Test

Start up JMP

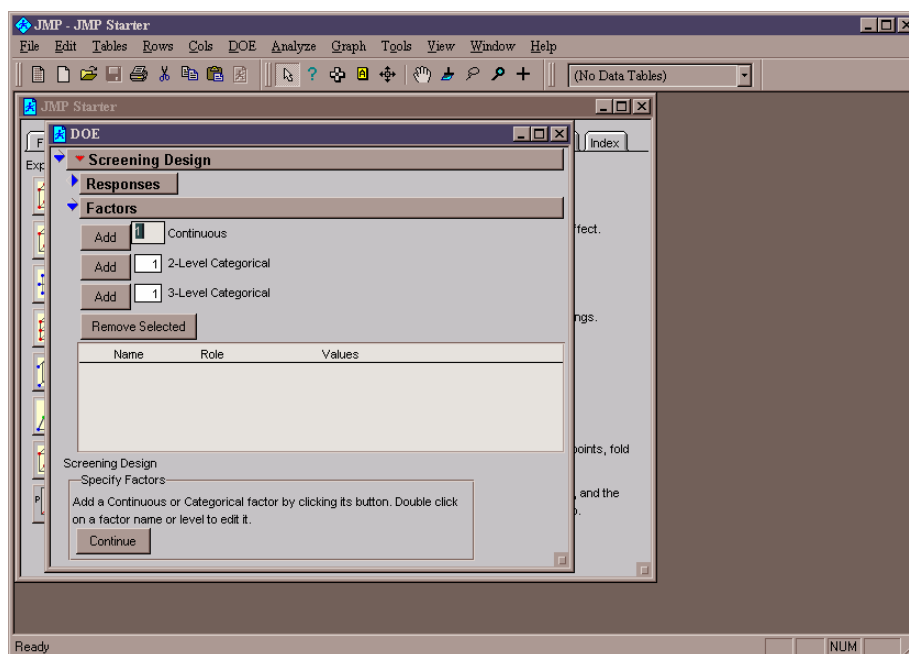
Go to the **JMP Starter** window. If the window doesn't come up when you start JMP, then go to **View** and select **JMP Starter** and the window below will come up.



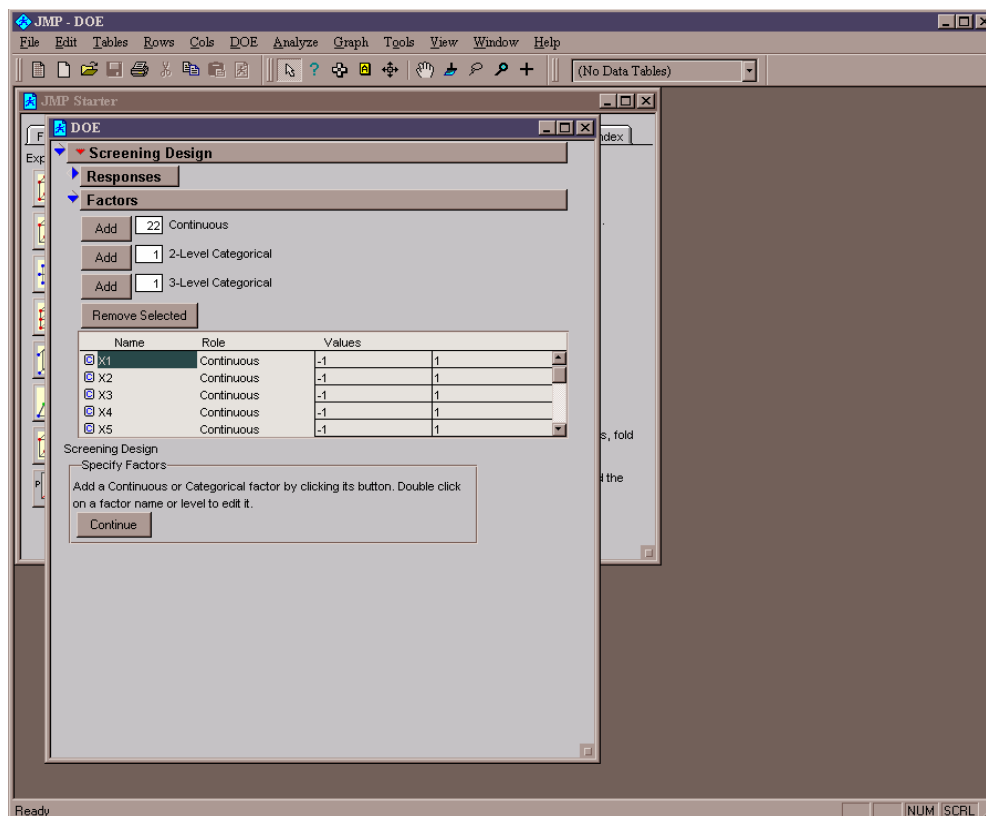
To create a Design of Experiments (DoE) table for a screening test go to **DOE** tab



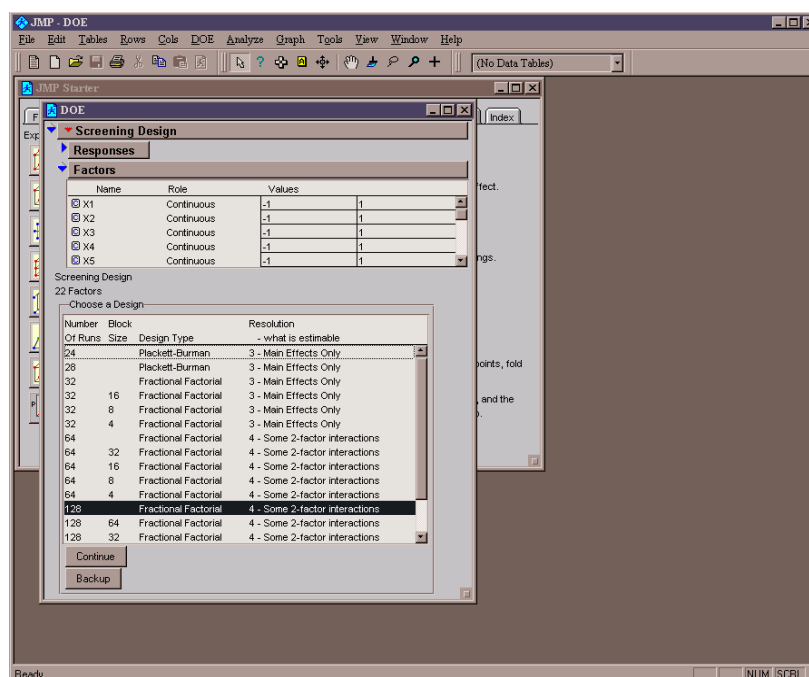
Then select the **Screening Design** button and add the number of continuous variables that you are considering. Let's add 22 variables.



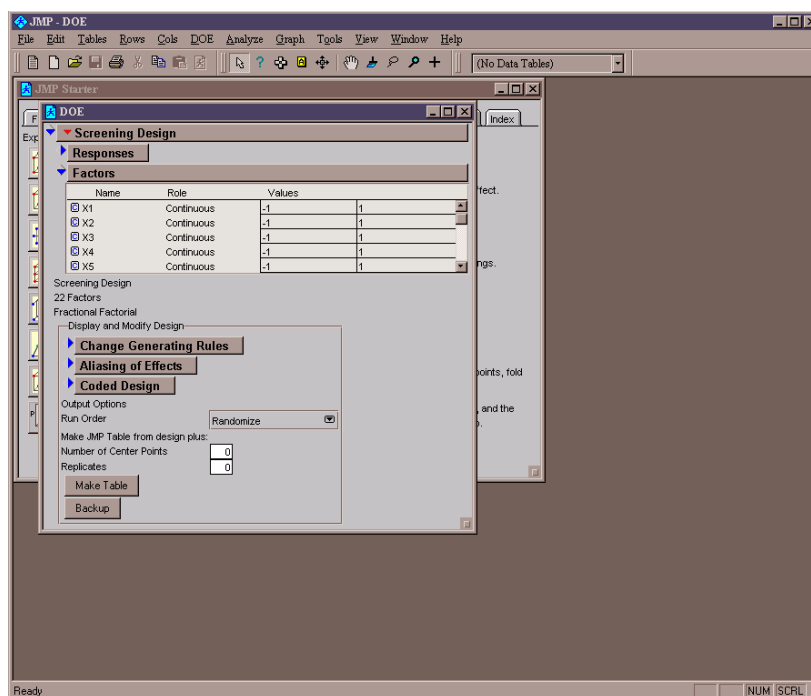
JMP will add X1 through X22 in the window that pops up. The variable ranges are set at a minimum of “-1” and a maximum of “1”. If you would like to change the names of the variables from X1 to something more intuitive, just double click on X1 and enter the variable name. Also, if you would rather look at a dimensional DoE, double click on the “-1” or “1” and add in the real values. Once you are done, click the **Continue** button.



In general, the larger number of runs is better, so choose a Fractional Factorial with a Resolution IV with some 2-factor interactions with no value in the block size column and then select the **Continue** button, or if you have messed up for some reason you can hit the **Back** button and it will take you to the previous screen.



The next screen will come up. There is a lot of information here. In particular, under the **Change Generating Rules** you can modify the choice of different fractional factorial designs for a given number of factors. The **Aliasing of Effects** button shows you the aliasing structure of the design you have selected and the **Coded Design** button shows you the pattern of high and low values for the factors in each run. For our purposes, the DoE that JMP will create is fine. We do need to add a few things before continuing. In particular, add 1 center point so that any quadratic effects could be simulated. And under the drop menu for “Run Order”, select the option “Keep the Same” rather than the default of “Randomize” so that you can always repeat the identical DoE in the future. Once you are done, select the **Make Table** button.

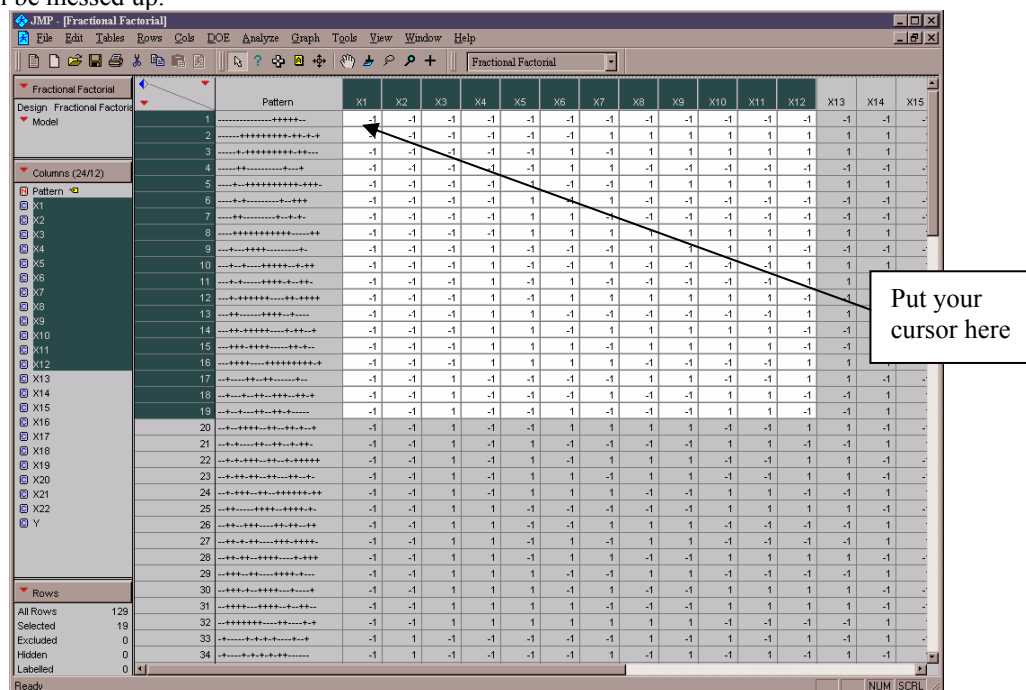


The following window will come up. This is your DoE for your screening test. If you did not enter in real values or names for your input variables then the table represents the non-dimensional settings of the 22 variables that you have (X1 through X22). It shows you that there are 129 rows which corresponds to the number of cases to be executed by your analysis code. In addition, the settings for the 22 variables that you have are shown, i.e. “-1” corresponds to the minimum setting of the variable, “+1” is the maximum value, and “0” is the midpoint. Note you can also change the labels on the columns to reflect the actual variable names that you have. You can do this by double clicking on the X1 column heading. You can then change the name and tab over to change the rest.

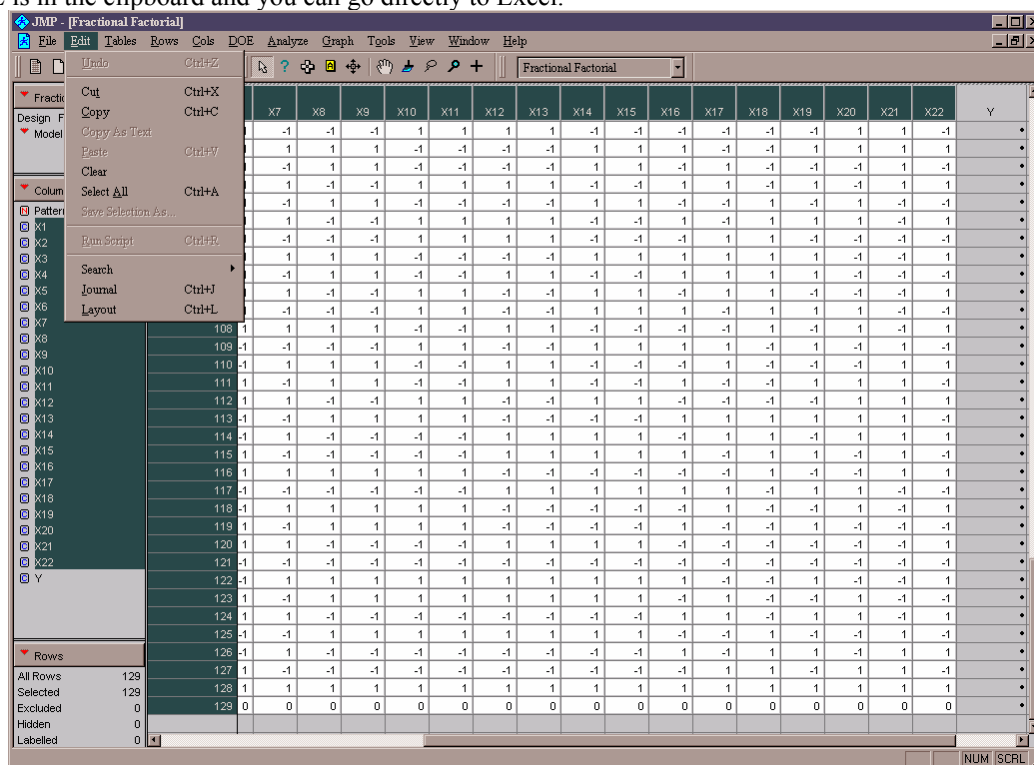
The screenshot shows the JMP - Fractional Factorial window. The 'Coded Design' table is displayed. The table has 129 rows and 22 columns (X1 through X22). The values are -1, 0, or 1, representing the coded levels for each factor. The 'Pattern' column shows the sequence of runs. The 'All Rows' section at the bottom indicates 129 rows are selected.

Pattern	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21	X22
1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
5	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
6	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
7	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
8	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
9	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
10	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
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12	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
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31	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
32	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
33	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
34	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

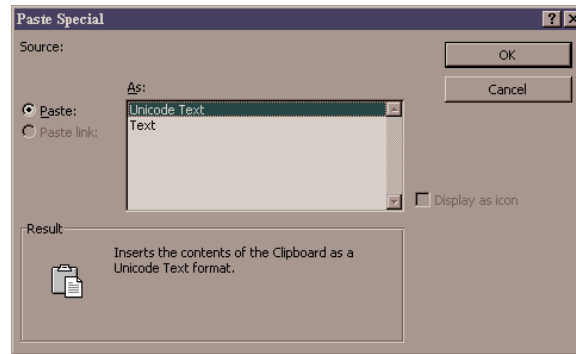
Now, what you need to actually run your analysis tool is the setting for the different variables for each case in the DoE, i.e., and actual values not non-dimensional ones. If you place the mouse cursor in the cell under “X1” and row 1, you can highlight the entire DoE table and then copy it into Excel. Below is shown a sample of a highlight. If I were to copy this and then paste it into Excel, I would get all the info for X1 through X12 and rows 1 through 19. You want the entire DoE table. NOTE: make sure that your copy and paste areas are the same dimensions. If they are not, your results will be messed up.



To copy the entire table, highlight all cells as shown below and then go to **Edit** and then click **Copy**. The entire DoE is in the clipboard and you can go directly to Excel.



You will be given an Excel spreadsheet entitled “convert_screening” which will take the above non-dimensional table from JMP and convert the design variables to real values to use in the command line *rundoe*. Open the “convert_screening” file and make the active cell C10. Then go under **Edit** and select **Paste Special** and you will get the following window, select Unicode Text or Text, and press **OK**. NOTE: look at the dimensions of the table you have in the “convert_screening” Excel file and make sure you have the right number of columns for the variables and the number of rows for the number of cases. If you have more or less than either one of these, you need to increase or decrease the dimensions by copying or deleting the cells or adding more columns, etc before you paste the JMP DoE table.



And you will see that the table you selected in JMP will fill out the table in Excel. What you see here is the non-dimensional table with the variables listed above (e.g. Wing area, T/W, TIT, etc.) and the corresponding “real value” ranges if you scroll to the right. The minimum value for the wing area is 7500 that corresponds to the “-1” of the JMP table. The maximum value is 9000 that is the “+1” value of JMP. You need to input your design variable names and ranges as applicable to your problem. Also note that the mid-point (i.e., “0”) is automatically calculated from the “-1” and “1” values you entered.

NOTE: The current dimensions of the conversion are 22 by 129. Modify if larger or smaller by adding rows and columns to both the JMP table below AND the dimensional to the right!!!

	Case	Wing Area	T/W	TIT	FPR	OPR	throttle Rati	CLdes	X2	X3	X4	X5
1	1	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
2	2	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
3	3	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
4	4	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
5	5	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
6	6	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
7	7	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
8	8	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
9	9	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
10	10	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
11	11	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
12	12	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
13	13	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
14	14	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
15	15	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
16	16	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
17	17	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
18	18	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
19	19	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
20	20	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
21	21	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
22	22	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
23	23	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
24	24	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
25	25	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000
26	26	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000	-100000

Now, if you scroll over to the right, you will see the real number DoE values that were converted from the non-dimensional JMP table as shown below.

Microsoft Excel - convert_screening

File Edit View Insert Format Tools Data Window Cell Run Help

Times New Roman 10 B I U

C10 = -1

X Y Z AA AB AC AD AE AF AG AH AI AJ

1
2 X'w
3
4 0.22
5 0.25
6 0.28

Real Numbers to use in the Command line DoE for your analysis tool

Case Wing Area T/W TIT FPR OPR Throttle Rati CLdes X2 X3 X4

10	-1.00000	1	7500.000	0.290	3000.000	3.500	18.000	1.040	0.080	1.540	2.100	2.400	2.
11	1.00000	2	7500.000	0.290	3000.000	3.500	18.000	1.040	0.120	1.690	2.360	2.580	2.
12	-1.00000	3	7500.000	0.290	3000.000	3.500	18.000	1.050	0.080	1.690	2.360	2.580	2.
13	1.00000	4	7500.000	0.290	3000.000	3.500	18.000	1.050	0.120	1.540	2.100	2.400	2.
14	-1.00000	5	7500.000	0.290	3000.000	3.500	21.000	1.040	0.080	1.690	2.360	2.580	2.
15	1.00000	6	7500.000	0.290	3000.000	3.500	21.000	1.040	0.120	1.540	2.100	2.400	2.
16	-1.00000	7	7500.000	0.290	3000.000	3.500	21.000	1.050	0.080	1.540	2.100	2.400	2.
17	1.00000	8	7500.000	0.290	3000.000	3.500	21.000	1.050	0.120	1.690	2.360	2.580	2.
18	-1.00000	9	7500.000	0.290	3000.000	4.500	18.000	1.040	0.080	1.690	2.360	2.580	2.
19	1.00000	10	7500.000	0.290	3000.000	4.500	18.000	1.040	0.120	1.540	2.100	2.400	2.
20	-1.00000	11	7500.000	0.290	3000.000	4.500	18.000	1.050	0.080	1.540	2.100	2.400	2.
21	1.00000	12	7500.000	0.290	3000.000	4.500	18.000	1.050	0.120	1.690	2.360	2.580	2.
22	-1.00000	13	7500.000	0.290	3000.000	4.500	21.000	1.040	0.080	1.540	2.100	2.400	2.
23	1.00000	14	7500.000	0.290	3000.000	4.500	21.000	1.040	0.120	1.690	2.360	2.580	2.
24	-1.00000	15	7500.000	0.290	3000.000	4.500	21.000	1.050	0.080	1.690	2.360	2.580	2.
25	1.00000	16	7500.000	0.290	3000.000	4.500	21.000	1.050	0.120	1.540	2.100	2.400	2.
26	-1.00000	17	7500.000	0.290	3400.000	3.500	18.000	1.040	0.080	1.690	2.360	2.400	2.

Sum=-52.00000 NUM SCRL

You need to copy this tables from cell Z10 (or wherever the cell is that corresponds to the case number) to the bottom right of the converted table as shown below.

Microsoft Excel - convert_screening

File Edit View Insert Format Tools Data Window Cell Run Help

Times New Roman 10 B I U

Z10 = 1

AK AL AM AN AO AP AQ AR AS AT AU AV AW

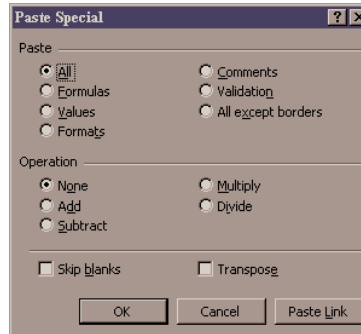
7 X5 X6 Y2 Y5 t/c_root t/c_tip SHref SVref XNASCAL YD2 YD1 X'w

9

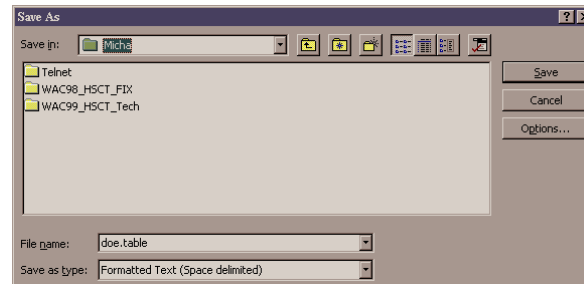
116	2.370	2.180	0.440	0.600	5.000	4.000	400.000	550.000	1.100	0.550	0.240	0.220
117	2.190	2.500	0.580	0.430	3.000	2.000	400.000	550.000	0.900	0.550	0.240	0.280
118	2.370	2.180	0.440	0.600	5.000	4.000	700.000	350.000	1.100	0.490	0.300	0.220
119	2.190	2.500	0.580	0.430	3.000	2.000	700.000	350.000	0.900	0.490	0.300	0.280
120	2.190	2.500	0.580	0.430	3.000	4.000	400.000	350.000	1.100	0.550	0.300	0.220
121	2.370	2.180	0.440	0.600	5.000	2.000	400.000	350.000	0.900	0.550	0.300	0.280
122	2.370	2.180	0.440	0.430	3.000	4.000	700.000	550.000	1.100	0.550	0.300	0.220
123	2.190	2.500	0.580	0.600	5.000	2.000	700.000	550.000	0.900	0.550	0.300	0.280
124	2.190	2.500	0.580	0.600	5.000	4.000	400.000	550.000	1.100	0.490	0.300	0.220
125	2.370	2.180	0.440	0.430	3.000	2.000	400.000	550.000	0.900	0.490	0.300	0.280
126	2.190	2.500	0.580	0.600	5.000	4.000	700.000	350.000	1.100	0.550	0.240	0.220
127	2.370	2.180	0.440	0.430	3.000	2.000	700.000	350.000	0.900	0.550	0.240	0.280
128	2.370	2.180	0.440	0.430	3.000	4.000	400.000	350.000	1.100	0.490	0.240	0.220
129	2.190	2.500	0.580	0.600	5.000	2.000	400.000	350.000	0.900	0.490	0.240	0.280
130	2.190	2.500	0.440	0.430	3.000	2.000	400.000	350.000	0.900	0.490	0.240	0.220
131	2.370	2.500	0.580	0.600	5.000	4.000	400.000	350.000	1.100	0.490	0.240	0.280
132	2.370	2.500	0.580	0.600	5.000	2.000	700.000	350.000	0.900	0.550	0.240	0.220
133	2.190	2.180	0.440	0.430	3.000	4.000	700.000	350.000	1.100	0.550	0.240	0.280
134	2.370	2.500	0.580	0.600	5.000	2.000	400.000	550.000	0.900	0.490	0.300	0.220
135	2.190	2.180	0.440	0.430	3.000	4.000	400.000	550.000	1.100	0.490	0.300	0.280
136	2.190	2.180	0.440	0.430	3.000	2.000	700.000	550.000	0.900	0.550	0.300	0.220
137	2.370	2.500	0.580	0.600	5.000	4.000	700.000	550.000	1.100	0.550	0.300	0.280
138	2.280	2.340	0.510	0.515	4.000	3.000	550.000	450.000	1.000	0.520	0.270	0.250

Sum=1620365.775 NUM SCRL

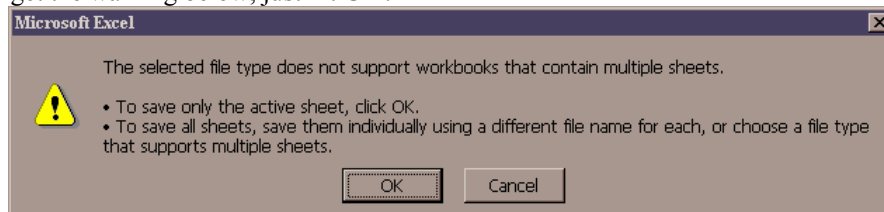
Now, open a new sheet and go to **Edit** and the **Paste Special**. And the following window will come up. You want to select **Values** and then **OK**.



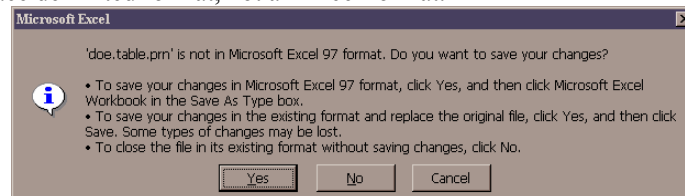
Your values will be pasted into a 22 by 129 range. Now go to **File** and then **Save As** and you will get a “Save As” window. Under **Save as type**, choose the “Formatted Text (Space delimited)” option and call your file “doe.table”. Then hit the **Save** button.



You will get the warning below, just hit **OK**.



Then go to **File** and select **Close**. You will get another warning as shown below. Select the **No** option because you want the file in the space delimited format, not an Excel format.



Now you need to FTP this file to your account to run your analysis code. Make sure you FTP as ASCII NOT binary. I assume you know how to do this. Then you need to set up your “rundoe” script. An example script for an HSCT design space is shown below. You will create one similar to this on your UNIX account. Call the file *rundoe*. Additionally, when you ftp your doe.table file to your account, make sure that there are spaces between each number. In our case, we should have 23 columns of numbers and 129 rows. If your file did not transfer as such, go back to Excel and copy your table again to a new worksheet and increase the column width so that you see spaces between the numbers and then save the file again.

```
#!/usr/local/bin/tcl -f
for_file line doe.table {
    lassign $line a var1 var2 var3 var4 var5 var6 var7 var8 var9 var10 var11 var12 var13 var14 var15 var16
    puts stdout "##### CASE # $a #####"
# Set up the input to tsw
    set file [open varfile w]
    puts $file "CONFIN SW $var1 "
    puts $file "CONFIN TWR $var2 "
    puts $file "CONFIN ETIT $var3 "
    puts $file "CONFIN EFPR $var4 "
    puts $file "CONFIN EOPR $var5 "
    puts $file "DESIGN CLDESIGN $var6 "
    puts $file "DESIGN X2 $var7 "
```



```

        puts $file "DESIGN X3 $var8 "
        puts $file "DESIGN X4 $var9 "
        puts $file "DESIGN X5 $var10 "
        puts $file "DESIGN X6 $var11 "
        puts $file "DESIGN Y2 $var12 "
        puts $file "DESIGN TCRT $var13 "
        puts $file "DESIGN TCTP $var14 "
        puts $file "DESIGN SHREF $var15 "
        puts $file "DESIGN SVREF $var16 "
        close $file
# Run tsw
puts stdout "    Running tsw"
catch "exec tsw -input opt_baseline -output case$a varfile"
exec cp case$a fl98.in
exec frops_subs_modified
exec mv fropsin.new case$a
}
exit

```

Make sure your baseline file name that you are using corresponds to this name

Another sample file is shown below.

```

#!/usr/local/bin/tcl -f
for_file line doe.table {
    lassign $line i var1 var2 var3 var4 var5 var6
    puts stdout "##### CASE # $i #####"
# Set up the input to tsw
    set file [open varfile w]
    puts $file "MAININ THRSO $var1 "
    puts $file "TOLIN THRTO\[1\] $var1 "
    puts $file "TOLIN THRTO\[2\] $var1 "
    puts $file "TOLIN THRTO\[3\] $var1 "
    puts $file "TOLIN THRTO\[4\] $var1 "
    puts $file "TOLIN THRTO\[5\] $var1 "
    puts $file "TOLIN THRTO\[6\] $var1 "
    puts $file "TOLIN THRTO\[7\] $var1 "
    puts $file "TOLIN THRTO\[8\] $var1 "
    puts $file "TOLIN THRTO\[9\] $var1 "
    puts $file "TOLIN THRTO\[10\] $var1 "
    puts $file "MAININ GW $var2 "
    set land_wt [expr ($var2-381987.4)]
    puts $file "MAININ WLDG $land_wt "
    puts $file "MAININ CLTOM $var3 "
    puts $file "TOLIN CLTOM $var3 "
    puts $file "MAININ CLLDM $var4 "
    puts $file "TOLIN CLLDM $var4 "
    puts $file "TOLIN ALPROT $var5 "
    puts $file "TOLIN ALMXLD $var6 "
    close $file
# Run tsw
    puts stdout "    Running tsw"
    catch "exec tsw -input base -output case$i varfile"
}
exit

```

This syntax is based on THRTO having a 10 element array and this is how you substitute a particular element of that array

Now you need to write another script to run your DoE. A simple script is shown below. You can call the file anything you like. Just make sure that you change the mode of the file to make it executable. For example, if you call the file *runcases*, then at the UNIX prompt, type `chmod 700 runcases`. Also, do this for the *rundoe* file you created.

```

echo "Running the bl script for DoE cases"
i=1
imax=129
while [ $i -le $imax ]
do
    echo "Now running file: $i"
    frops case$i case$i.out
    echo "$i completed"
    echo "*****"
    let i=i+1
done

```

To execute both the *rundoe* and the *runcases*, you simply need to type the file name and the script will run. You want to run the *rundoe* first and create all your case files and then run the *runcases* to execute FLOPS. Just a reminder, your baseline file is called *opt_baseline* in the first *rundoe* script and *base* in the second. Make sure you have the baseline file and the *doe.table* file in the directory that you are running the script.

Now, you will need to extract the metric data for each case. To do so, you will use the *parse98* program. A sample file is shown below. I call this file *getinfo*. You also need to change the mode of the file as you did above. NOTE, make sure you are parsing the proper info before you run this script. You can check this by executing a given line at the UNIX command prompt. For example,

```

parse98 -search "TOGW" -read 3 -occurance 1 -offset 0 case1.out

#!/usr/local/bin/wishx -f

set Number_of_Cases 289
exec touch summary_total
exec rm summary_total

exec touch noise_summary
exec rm noise_summary

exec echo " TOGW TOFL LDGFL VAPP ACQ RDTE RPM TAROC DOC+I" >> summary_total
exec echo " THRUST TOGW K2T K2A K1A WLDG" >> noise_summary
for {set i 1} { $i <= $Number_of_Cases } { incr i 1 } {
    puts stdout "getting info case$i"
    set togw [ exec parse98 -search "TOGW" -read 3 -occurance 1 -offset 0 case$i.out ]
    set tofl [ exec parse98 -search "DFAROFF" -read 3 -occurance 1 -offset 0 case$i.out ]
    set ldgfl [ exec parse98 -search "DFARLDG" -read 3 -occurance 1 -offset 0 case$i.out ]
    set vapp [ exec parse98 -search "DVAPP" -read 3 -occurance 1 -offset 0 case$i.out ]
    set acq [ exec parse98 -search "Final" -read 7 -occurance 1 -offset 0 case$i.out ]
    set rdte [ exec parse98 -search "TOTAL RDT&E COST" -read 4 -occurance 1 -offset 0 case$i.out ]
    set rpm [ exec parse98 -search "Average Yield/RPM" -read 4 -occurance 1 -offset 0 case$i.out ]
    set taroc [ exec parse98 -search "Method SubTotal" -read 5 -occurance 1 -offset 0 case$i.out ]
    set doci [ exec parse98 -search "Method SubTotal" -read 4 -occurance 1 -offset 0 case$i.out ]

    set thrust [ exec parse98 -search "DTHRUST" -read 3 -occurance 1 -offset 0 case$i.out ]
    set k2t [ exec parse98 -search "K2T =" -read 3 -occurance 1 -offset 0 case$i.out ]
    set k2a [ exec parse98 -search "K2A =" -read 3 -occurance 1 -offset 0 case$i.out ]
    set k1a [ exec parse98 -search "K1A =" -read 3 -occurance 1 -offset 0 case$i.out ]
    set wldg [ exec parse98 -search "MAXIMUM LANDING WEIGHT" -read 4 -occurance 1 -offset 0 case$i.out ]

    exec echo "$i $togw $tofl $ldgfl $vapp $acq $rdte $rpm $taroc $doci" >> summary_total
    exec echo "$i $thrust $togw $k2t $k2a $k1a $wldg" >> noise_summary
}

puts stdout "Parsing is now completed!!"

exit

```

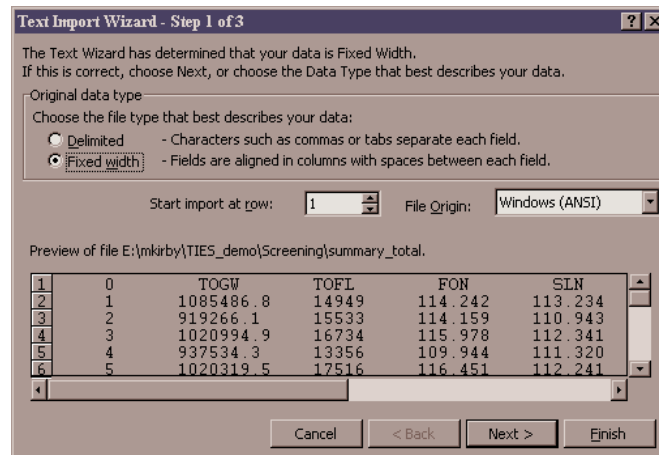
You should get the TOGW value from case1.out. This command is looking for the character string "TOGW" (-search), for the first time it occurs (-occurance 1), looking on the same line that parse98 finds "TOGW" (-offset 0), getting the 3rd character string on that line (-read 3), and will return that value to the screen. Do this for each metric to make sure you are getting the right values. All of your data will be extracted and put into a file called *summary_total*. A sample of one of these files is shown below for the first 12 cases. You need to ftp this back to your PC and then open in Excel.

```

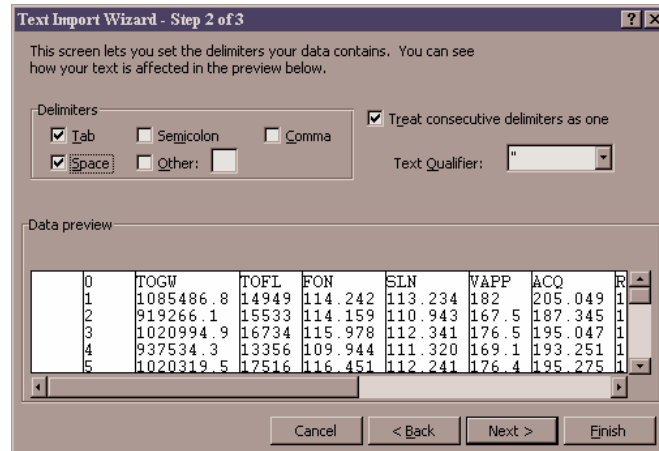
TOGW TOFL VAPP FON SLN ACQ RDTE RPM
1 1085486.8 14949 182 114.242 113.234 205.049 16850.698 0.13147
2 919266.1 15533 167.5 114.159 110.943 187.345 15240.811 0.11494
3 1020994.9 16734 176.5 115.978 112.341 195.047 15806.297 0.12553
4 937534.3 13356 169.1 109.944 111.32 193.251 16021.355 0.11602
5 1020319.5 17516 176.4 116.451 112.241 195.275 15820.057 0.12552
6 955509.4 13322 170.7 110.159 111.527 194.7 16143.683 0.1181
7 1028392.3 14247 177.1 112.5 112.526 199.759 16433.2 0.12553
8 860729.5 14323 162 112.585 110.359 181.794 14819.3 0.10916
9 951218 14090 170.3 112.972 111.292 193.578 16015.582 0.1176
10 1019691.4 15701 176.4 114.206 112.224 194.959 15808.73 0.12532
11 976201.8 15621 172.6 114.724 111.729 192.515 15641.596 0.12062
12 1018651.7 14374 176.3 112.924 112.345 198.327 16294.583 0.12447.....

```

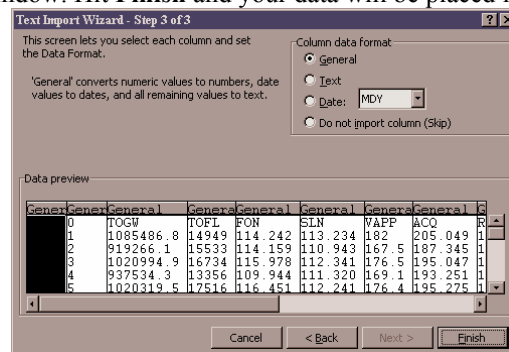
Now, open Excel and go to **File**, then **Open**, and then select “List all file types” and find the *summary_total* file that you ftp. You will get the following window. You want to open it as a **Delimited** character file. Select that option and hit **Next >**.



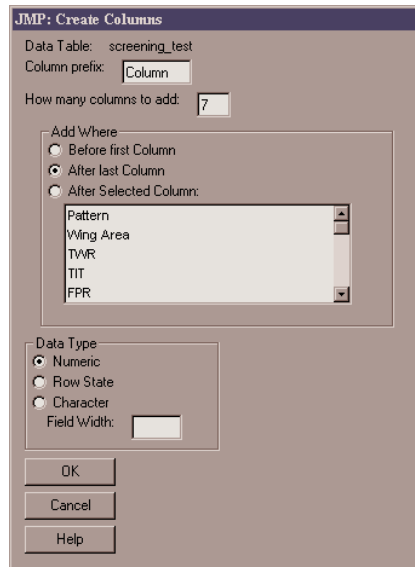
You will get the window below. You want to open it as delimited by **Tab** and **Space**. Then hit **Next**.



You will get the below window. Hit **Finish** and your data will be placed into separate cells.



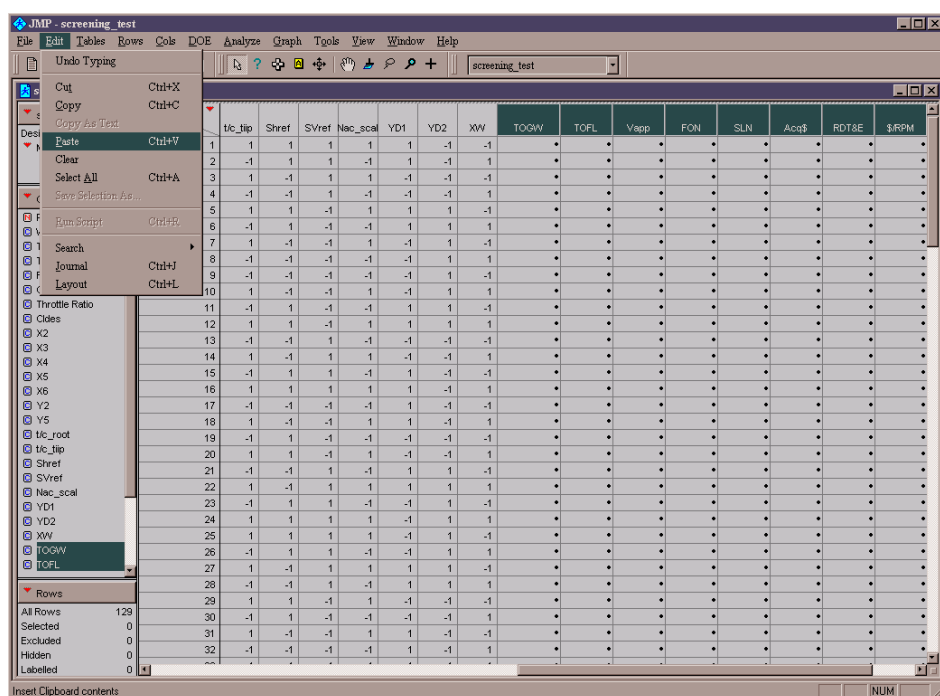
Now select all the data and copy it back to JMP so that you can look at the influence of each design variable on the metrics (or responses) of interest. Highlight all the data and copy. Open JMP and recreate your DoE. You will need to add more columns for your data. To do this, go to **Cols** and then select **Add Multiple Columns...** and you will get the following window. The DoE table has one response column entitled “Y”. For the example I am showing here, there are 8 responses. Hence, we need to add 7 columns “After last Column” and then hit **OK**.



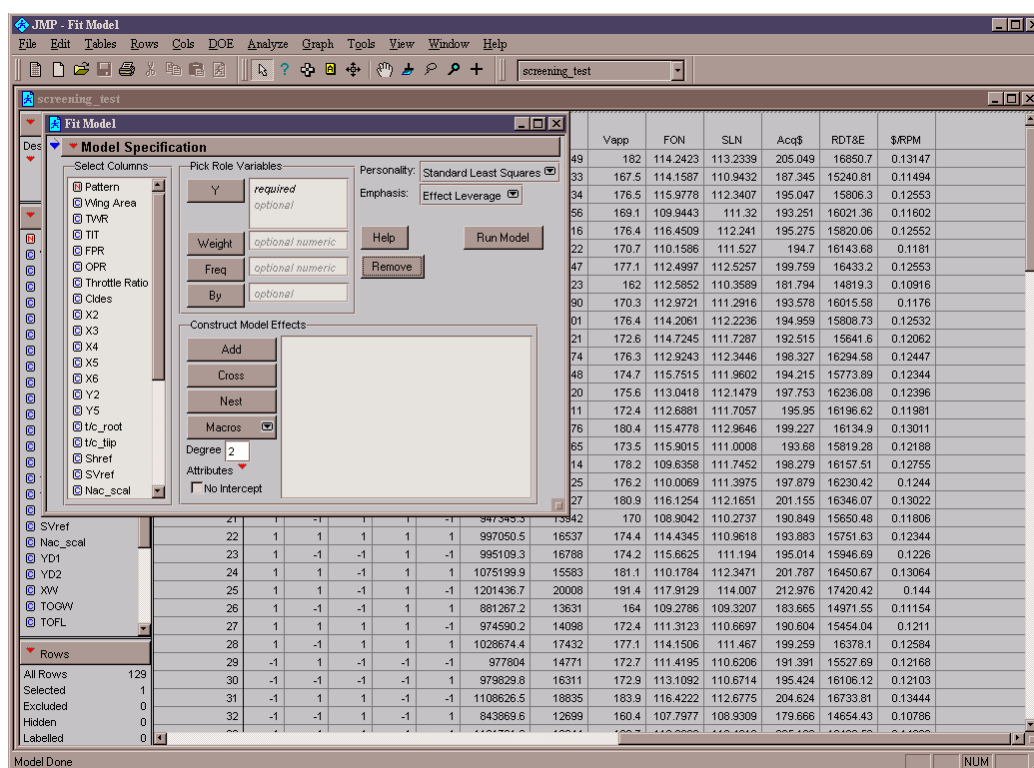
As you see below, 7 columns were added at the end. You can change the names of the columns just as you did with the design variables described previously.

	UC_Rp	Shret	Srvret	Hac_scol	YD1	YD2	XW	Y	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
1	1	1	1	1	1	1	-1	-1	*	*	*	*	*	*	*
2	-1	1	1	-1	1	-1	1	*	*	*	*	*	*	*	*
3	1	-1	1	1	-1	-1	-1	*	*	*	*	*	*	*	*
4	-1	-1	1	-1	-1	-1	1	*	*	*	*	*	*	*	*
5	1	1	-1	1	1	1	-1	*	*	*	*	*	*	*	*
6	-1	1	-1	-1	1	1	1	*	*	*	*	*	*	*	*
7	1	-1	-1	1	-1	1	-1	*	*	*	*	*	*	*	*
8	-1	-1	-1	-1	-1	1	1	*	*	*	*	*	*	*	*
9	-1	-1	-1	-1	-1	1	-1	*	*	*	*	*	*	*	*
10	1	-1	-1	1	-1	1	1	*	*	*	*	*	*	*	*
11	-1	1	-1	-1	1	1	-1	*	*	*	*	*	*	*	*
12	1	1	-1	1	1	1	1	*	*	*	*	*	*	*	*
13	-1	-1	1	-1	-1	-1	-1	*	*	*	*	*	*	*	*
14	1	-1	1	1	-1	-1	1	*	*	*	*	*	*	*	*
15	-1	1	1	-1	1	-1	-1	*	*	*	*	*	*	*	*
16	1	1	1	1	1	1	-1	*	*	*	*	*	*	*	*
17	-1	-1	-1	-1	1	-1	-1	*	*	*	*	*	*	*	*
18	1	-1	-1	1	1	1	-1	*	*	*	*	*	*	*	*
19	-1	1	-1	-1	-1	-1	-1	*	*	*	*	*	*	*	*
20	1	1	1	-1	1	-1	-1	*	*	*	*	*	*	*	*
21	-1	-1	1	-1	-1	1	1	*	*	*	*	*	*	*	*
22	1	-1	1	1	1	1	1	*	*	*	*	*	*	*	*
23	-1	1	1	-1	-1	1	-1	*	*	*	*	*	*	*	*
24	1	1	1	1	-1	1	1	*	*	*	*	*	*	*	*
25	1	1	1	1	-1	1	-1	*	*	*	*	*	*	*	*
26	-1	1	1	-1	-1	1	1	*	*	*	*	*	*	*	*
27	1	-1	1	1	1	1	-1	*	*	*	*	*	*	*	*
28	-1	-1	1	-1	1	1	1	*	*	*	*	*	*	*	*
29	1	1	-1	1	-1	-1	-1	*	*	*	*	*	*	*	*
30	-1	1	-1	-1	-1	-1	1	*	*	*	*	*	*	*	*
31	1	-1	-1	1	1	1	-1	*	*	*	*	*	*	*	*
32	-1	-1	-1	-1	-1	1	-1	*	*	*	*	*	*	*	*

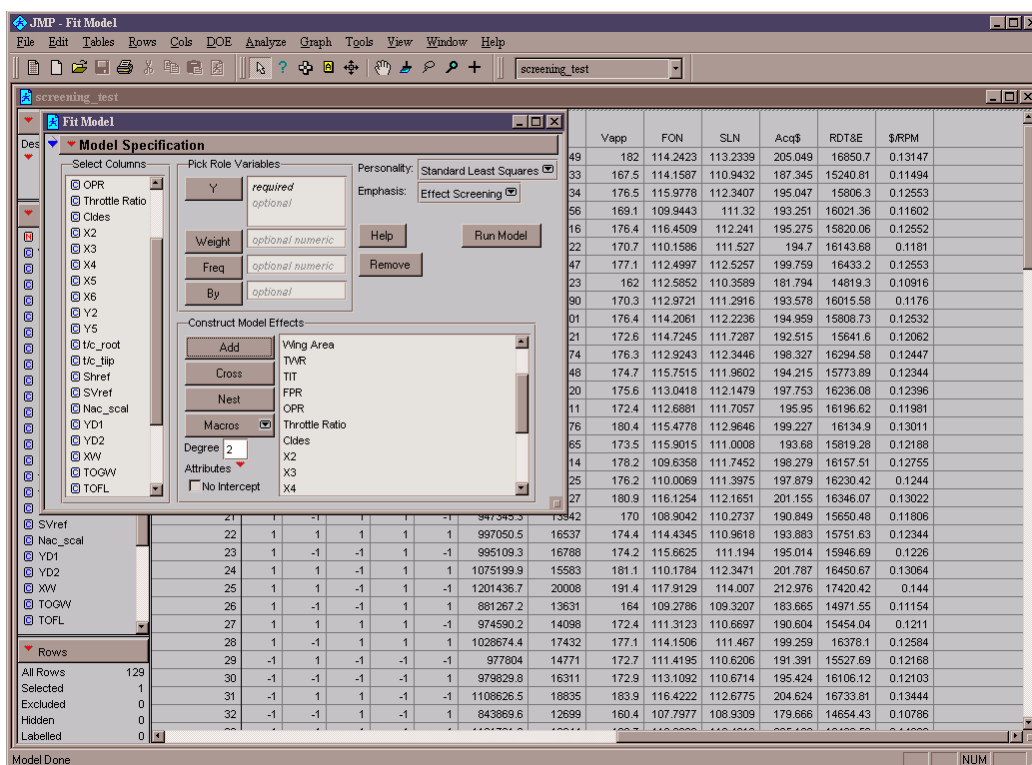
Now, highlight your response columns in JMP (as shown below) and go to **Edit** and then **Paste** and you will see that your response columns fill with the data that you copied from Excel.



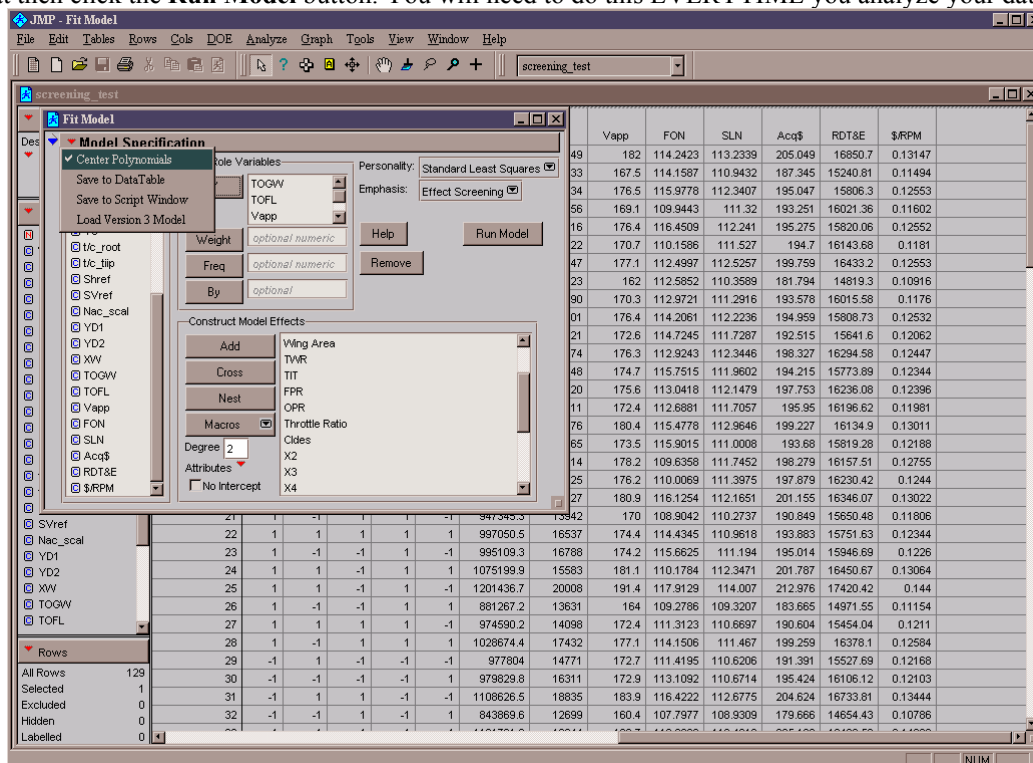
Now you need to analyze your data. Go to **Analyze** and select **Fit Model** and the following window will pop up. In the top left corner of the window are your variables. Click on your first variable (Wing_Area) and it will be highlighted. Then scroll down until you see your last design variable (XW). Hold down the shift key and then click on the last variable. You want to select the **Add** button.



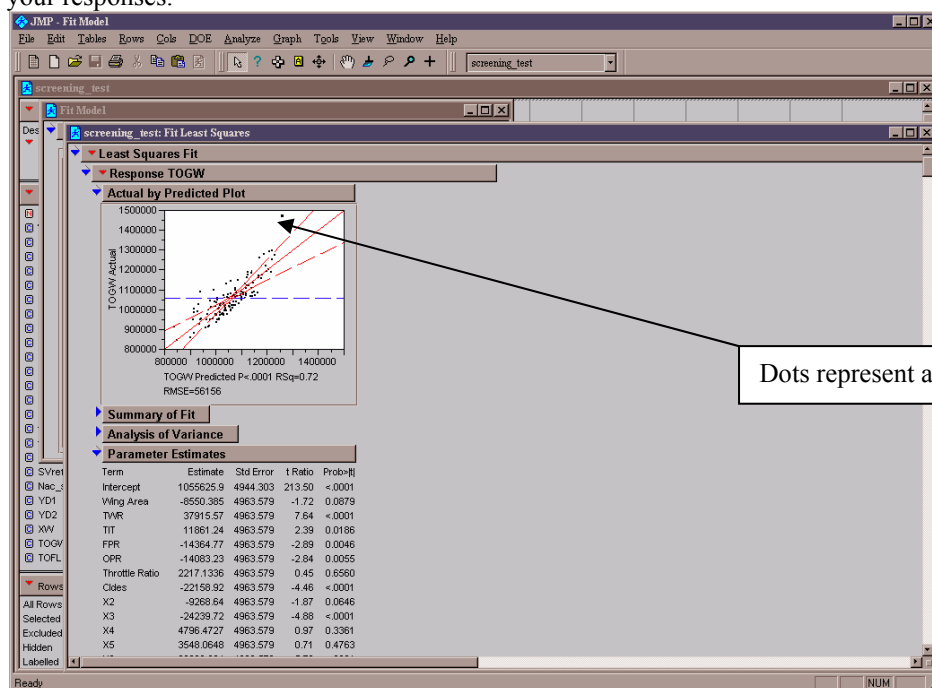
Your design variables will then be placed into the previously empty area under “Construct Model Effects”. In the same manner that you selected your design variables, select your responses and click on the **Y** button.



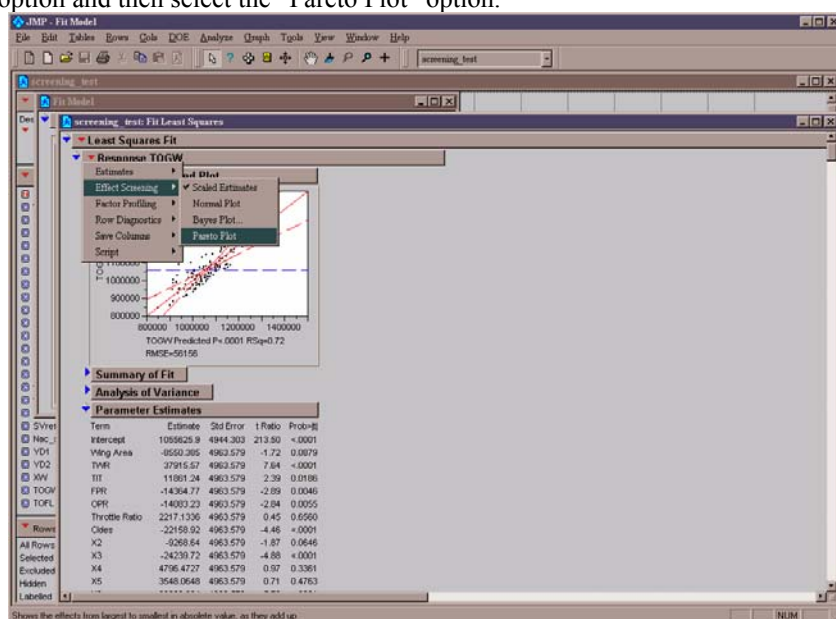
IMPORTANT: Now, go under the drop menu for **Model Specification** and unclick the “Center Polynomials” option. If this option is enabled a continuous term participating in a crossed term will be centered by its mean. Thus, your coefficients will not be simple numerical values. So unclick it to avoid difficulties. Once you have done that then click the **Run Model** button. You will need to do this EVERYTIME you analyze your data!!!



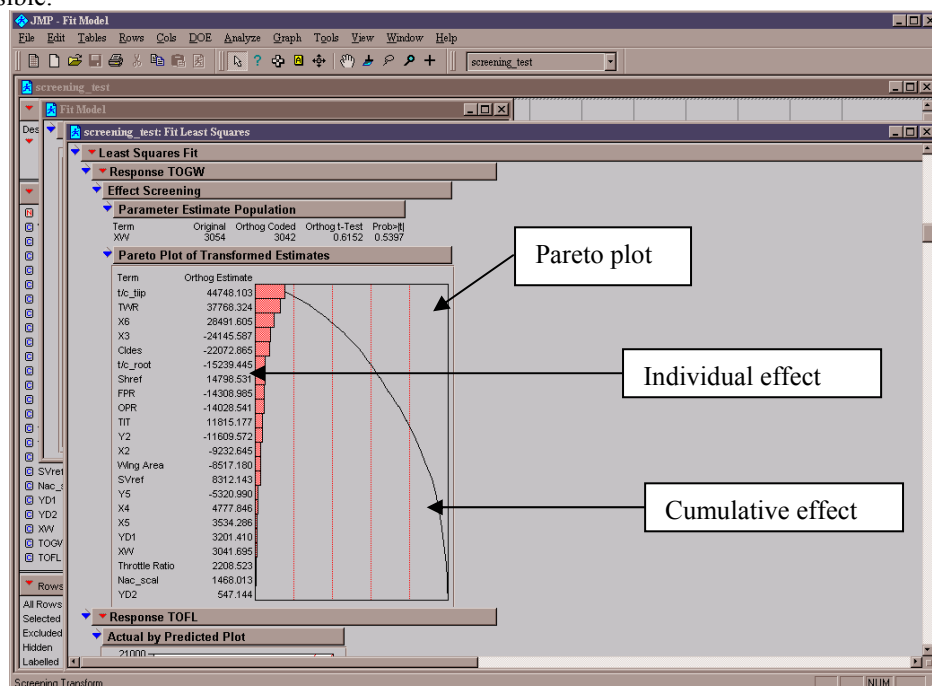
The following window will appear. Your responses will be listed in the order in which you entered them in the **Fit Model** window. In the example below, you will see the “Actual by Predicted Plot”. Each of the little dots in this plot represent one of the 129 cases you ran. If you put your mouse over a dot, JMP will tell you which case it corresponds to. Also, as you can see below, the dotted red lines correspond to how well your model is being predicted. The straight red line is indicative of a perfect model fit. The further away the dotted lines are from this “perfect” line implies that your analysis code is NOT being predicted very well by the model you chose. This large deviation is expected in a screening test since you are only trying to identify the main contributors to the responses from the use of a linear DoE. You are not actually trying to fit an RSE to the analysis code. However, if your analysis code was very linear, then the screening test would probably capture the variability quite well. Remember, the screening test is a linear model of your responses.



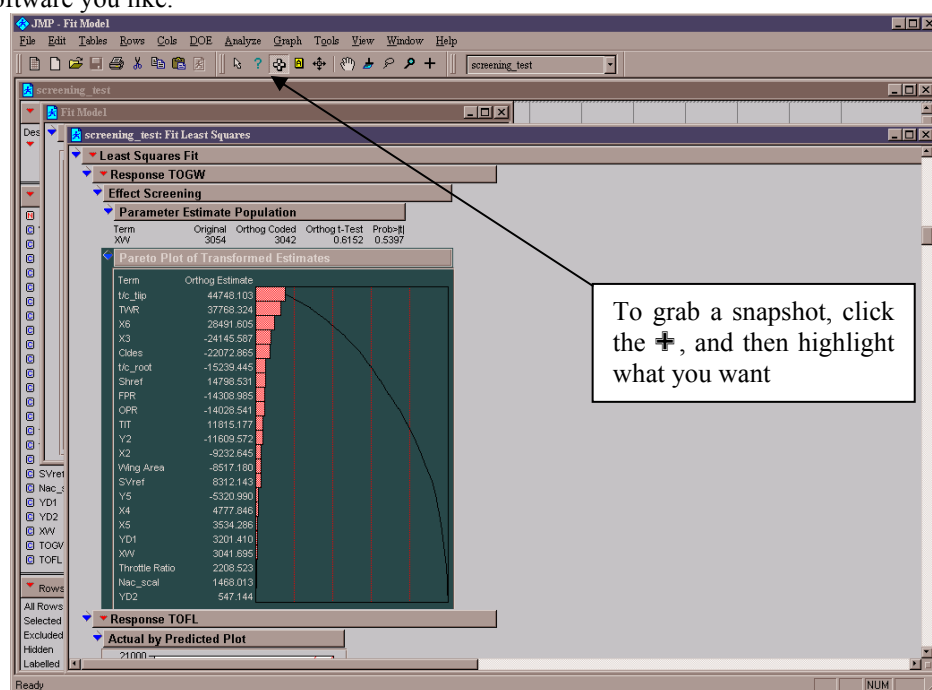
Now, we would like to know which of the 22 variables that we are considering actually contribute the most to our different responses. We can do this via a Pareto Analysis, which results in a Pareto plot. To view the Pareto plot for a response, click the little red ▼ by the “Response TOGW” drop menu and the following will appear. Click on the “Effect Screening” option and then select the “Pareto Plot” option.



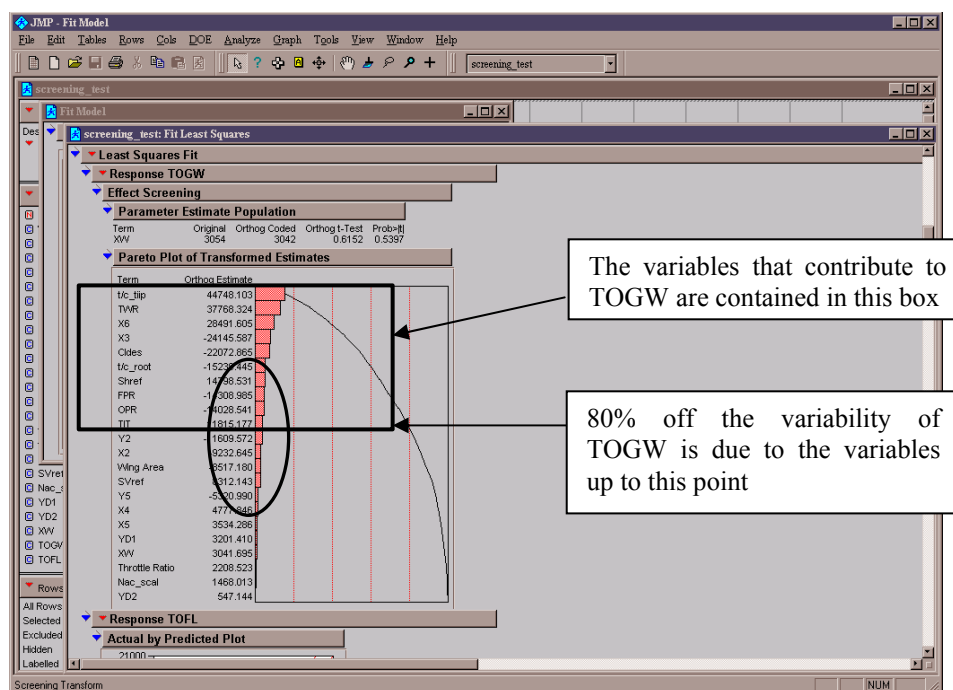
The Pareto plot shows the individual influence of each design variable on the response with the horizontal bars, and then the cumulative effect of the variables with the line. As you can see, the T/W and the t/c_tip are the two primary contributors to the TOGW, while X5 and Throttle Ratio hardly contribute at all. Here is where you can down select to the top 7, 8, or 11 main contributors and use those to create your RSEs. Do this for each of the responses and then you can identify which variables contribute to all the responses. For computational purposes, you would like to select a common set of variables such that you only have to run 1 DoE to capture all of the responses. However, this is not always possible.



You may want to copy the Pareto Plots to PowerPoint for presentation purposes. To do so, select the **+** icon in the menu bar and then click the bar that says “Pareto Plot of Transformed Estimates” or on the Pareto plot itself and you will see that the entire section is highlighted as below. Then go to **Edit** and select **Copy** and you can paste the image in any software you like.



Let's talk a little bit more about how you select the important contributing variables. In particular, based on the Pareto Principle, 80% of the variability in a response is due to 20% of the variables. So, for TOGW, one might select the variables that are contained in the box below. However, look at the individual effects of the variables that are contained in the oval. Each of the variables contribute about the same amount. In fact, their effects could be indistinguishable. This is where you need to use your engineering knowledge and experience as to which variables to choose. Since you are doing a screening test, you are only looking at linear effects and some variables may show up as significant, when in fact they are not. This is also due to the confounding structure of a linear DoE. Please refer to the JMP Help for more info on this. So, lesson learned...DON'T ARBITRARILY PICK VARIABLES WITHOUT FIRST UNDERSTANDING WHAT IS HAPPENING.



The Pareto Plot is a means to visually determine the most significant contributors to a response. However, you can also determine the important variables numerically. This information is actually provided as part of the fit model option. Consider the picture below. Without going into the mathematics behind the generation of the number below, let's put the definition into something more tangible. Under the Parameter Estimates bar, you see each of the variables you entered for the main effects of the fit model. Now, look at the two columns entitled “t Ratio” and “Prob>|t|”. The “t Ratio” column represents the ratio of the estimate to its standard error, or effectively the signal to noise ratio of that given parameter's influence to the response. The larger the number, the more influence that parameter estimate has on the response. You can also determine this by inspection of the “Prob>|t|” value in the next column. As a general rule of thumb, if this value is less than 0.05, then the parameter estimate significantly influences the response. If you compare the variables that had a value of less than 0.05 in the picture below to the Pareto plot generated above, you will find that the variables contained in the box of the Pareto Plot are the same. So, you could identify your significant contributors either way. But, if you had an enormous set of variables, you would probably want to choose the Pareto Plot to down select.

JMP - [screening test: Fit Least Squares]

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

screening_test

Least Squares Fit

Response TOGW

Summary of Fit

Analysis of Variance

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	1055625.9	4944.303	213.50	< 0.0001
Wing Area	-8550.385	4963.579	-1.72	0.0879
TWR	37915.57	4963.579	7.64	< 0.0001
TIT	11861.24	4963.579	2.39	0.0186
FPR	-14364.77	4963.579	-2.89	0.0046
OPR	-14083.23	4963.579	-2.84	0.0055
Throttle Ratio	2217.1336	4963.579	0.45	0.6560
CLdes	-22158.92	4963.579	-4.46	< 0.0001
X2	-9268.64	4963.579	-1.87	0.0646
X3	-24239.72	4963.579	-4.88	< 0.0001
X4	4796.4727	4963.579	0.97	0.3361
X5	3548.0648	4963.579	0.71	0.4763
X6	28602.684	4963.579	5.76	< 0.0001
Y2	-11654.83	4963.579	-2.35	0.0207
Y5	-5341.735	4963.579	-1.08	0.2843
t/c_root	-15298.86	4963.579	-3.08	0.0026
t/c_tip	44922.56	4963.579	9.05	< 0.0001
Shref	14856.226	4963.579	2.99	0.0034
SVref	8344.5492	4963.579	1.68	0.0957
Nac_scal	1473.7367	4963.579	0.30	0.7671
YD1	3213.8914	4963.579	0.65	0.5187
YD2	549.27734	4963.579	0.11	0.9121
XW	3053.5539	4963.579	0.62	0.5397

Effect Tests

Source	Noarm	DF	Sum of Squares	F Ratio	Prob > F
--------	-------	----	----------------	---------	----------

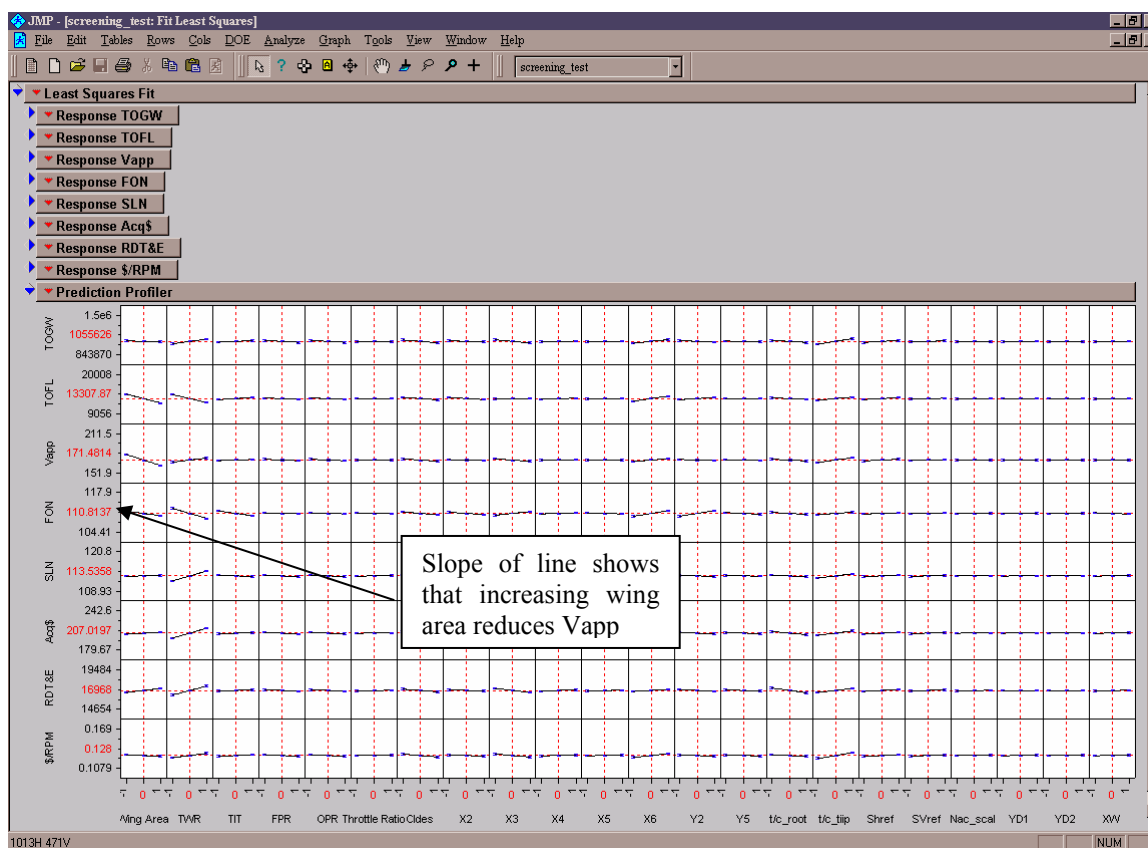
Ready

NUM

T Ratio is effectively a signal to noise ratio. The higher the value, the more the influence

If Prob>|t| is less than 0.05, the parameter significantly influences the response

Another important feature of JMP is the Prediction Profile feature as shown below. This should appear automatically when you fit your model. If it is not at the bottom of the window, then go to the drop menu at the top entitled “Least Squares Fit” and enable the drop menu, then select the “Profilers” option and then select the “Profile” option and scroll back down to the bottom of the window. On the left are the responses you have. Each of the bars is showing you the influence of a given design variable on the response. You could pick your variables from here, but when you get down to ones that “look” to have the same influence, the Pareto Plots help you make better decisions. The dotted vertical red lines will move if you left mouse click and drag. The line that you grab and move will change the variable setting (value shown in red) and then update the response value for the new variable setting. Play with this to get a feel for the Profiler.



Also with the Profiler, you can change the range of the variables and the responses. In effect, you can zoom in on a range or zoom out. You do this by putting your mouse over the name of the variable or the response, hold down the “Ctrl” button and then left mouse click. And the window below will come up for a response and the window below that will come up for an input variable.

JMP: Specify New Range for TOGW.

Specify New Range for TOGW.

Min: 843869.6

Max: 1466829.6

OK

Cancel

JMP: Current Settings for Wing Area

Current Value: 0

Minimum Setting: -1

Maximum Setting: 1

Number of Plotted Points: 100

Lock Factor Setting: ☐

OK

Cancel

That's pretty much it for the Screening test. For the variables that do not really contribute to the responses, you can set them at a value that minimizes or maximizes your responses. Although the impact is minimal, might as well help yourself as much as possible. Now you are ready for RSEs!!! Note, to avoid having to run a DoE for EACH metric, try to come up with a set of common variables that capture ALL metrics.

Creating Response Surface Equations

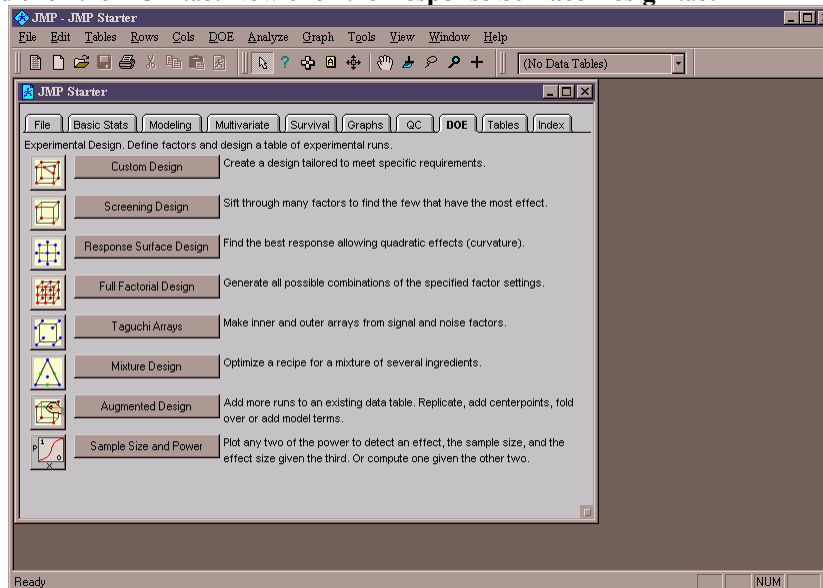
Once you have down-selected your variables to something more manageable, you are ready to create your RSE for your metrics or responses. These are calculated using the following equation:

$$R = b_o + \sum_{i=1}^k b_i k_i + \sum_{i=1}^k b_{ii} k_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^k b_{ij} k_i k_j$$

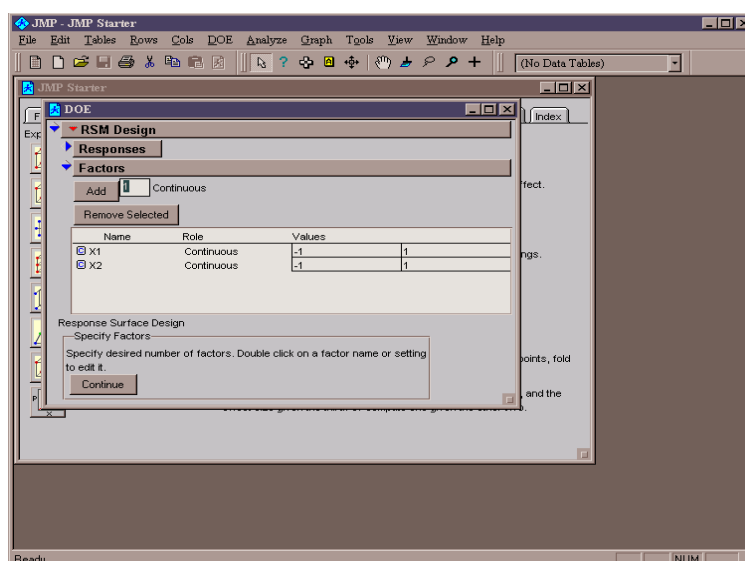
where b_i are regression coefficients for linear terms, b_{ii} are coefficients for pure quadratic terms, b_{ij} are coefficients for cross-product terms (second order interactions), and x_i, x_j are the design variables and $x_i x_j$ denotes interactions between two design variables.

You will go through most of the same steps as you did with the Screening test. The only differences will be with the type of DoE and the method for analyzing the data. So, let me describe those aspects and you can refer to the previous section for the other stuff.

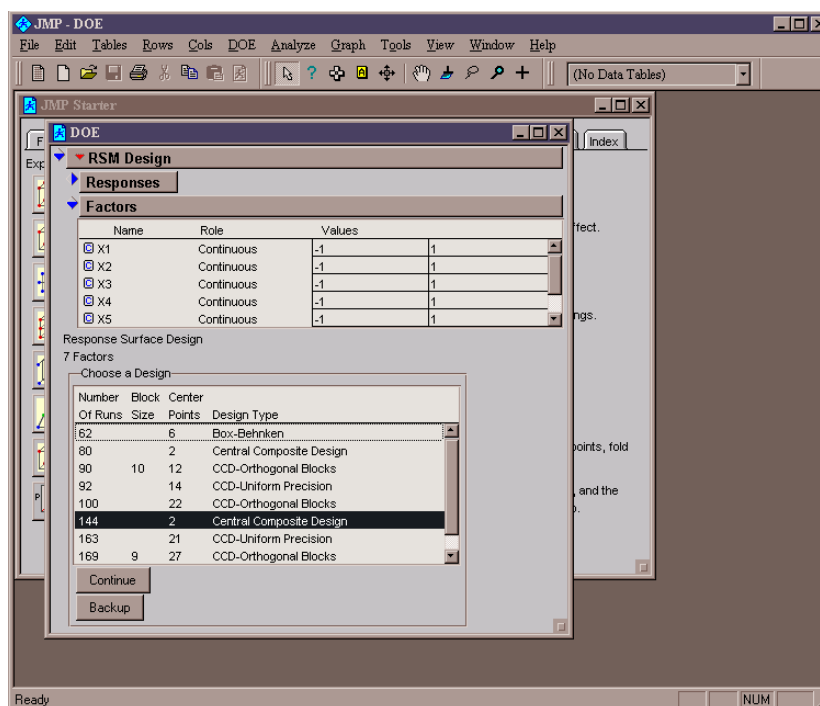
Let's say that we identified 7 variables that contribute to the responses of interest. Go back to JMP and go to the **JMP Starter** and click the **DOE** tab. Now click the **Response Surface Design** tab.



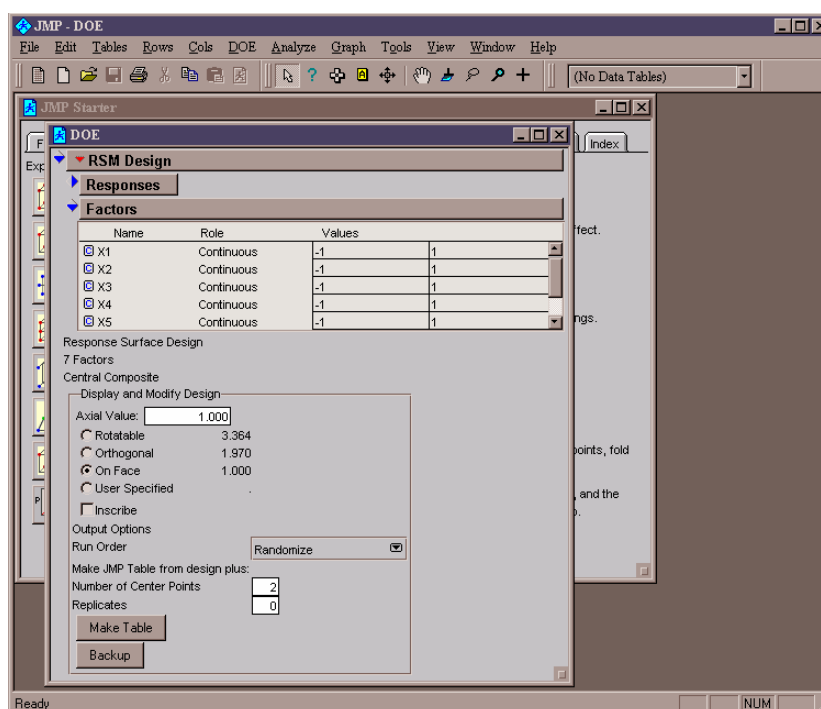
The following window will come up. As you did when you were creating the DoE for the screening test, add the number of variables and input the real names and values if you like. Say we have 7 variables, since the window already provides 2 variables, I just need to add 5. Then press **Continue**.



The following will come up. You will then get a bunch of DoE options as shown below. Typically, more runs are better since you have more data for the regression. So, let's pick the Central Composite Design (CCD) with 144 cases and 2 center points. Then hit **Continue**.



The window below will then open up. Note, the number of center points is there for when you are doing experiments that have noise, such as variations in a control environment. Since we are running computer simulations, the experiment is 100% repeatable and we will only need 1 center point. So, in the cell where the number of center points is defined as 2, change that to a 1. Also, if the "On Face" option is not selected for the design you chose, please select it. The reason for this is beyond the scope of this tutorial, but trust me, just select it. Again, change the **Run Order** to "Keep the Same" option as you did before. Then hit **Make Table**.



Your DoE table will open up. As shown below. Now, go through the same procedure that you did for the screening test.

1. copying your table to Excel,
2. convert to real numbers,
3. saving as *doe.table*,
4. ftp to your UNIX account,
5. modify your shell scripts for the new number of cases and variable names,
6. switch out variables, and
7. parse your data.

Bring the results back to Excel and import over to JMP. Now the difference is how you analyze the data.

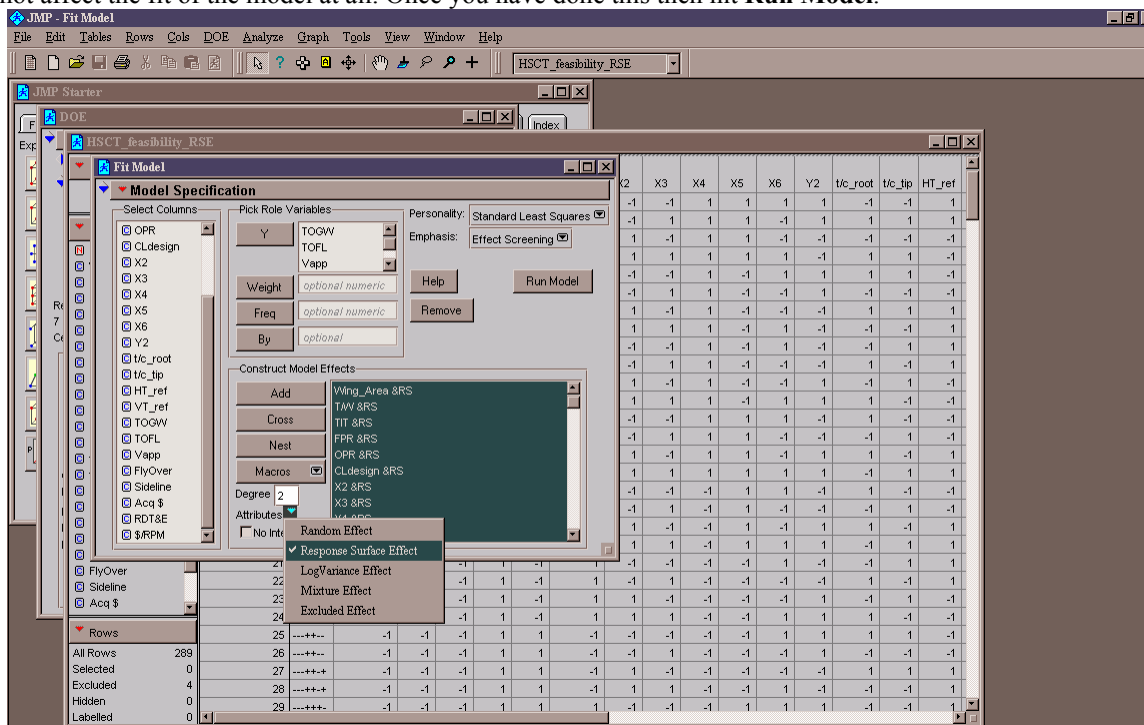
Pattern	X1	X2	X3	X4	X5	X6	X7	Y
1	-1	-1	-1	-1	-1	-1	-1	*
2	-1	-1	-1	-1	-1	-1	1	*
3	-1	-1	-1	-1	-1	1	-1	*
4	-1	-1	-1	-1	1	1	1	*
5	-1	-1	-1	-1	1	-1	-1	*
6	-1	-1	-1	-1	1	-1	1	*
7	-1	-1	-1	-1	1	1	-1	*
8	-1	-1	-1	-1	1	1	1	*
9	-1	-1	-1	1	-1	-1	-1	*
10	-1	-1	-1	1	-1	-1	1	*
11	-1	-1	-1	1	-1	1	-1	*
12	-1	-1	-1	1	-1	1	1	*
13	-1	-1	-1	1	1	-1	-1	*
14	-1	-1	-1	1	1	-1	1	*
15	-1	-1	-1	1	1	1	-1	*
16	-1	-1	-1	1	1	1	1	*
17	-1	-1	1	-1	-1	-1	-1	*
18	-1	-1	1	-1	-1	-1	1	*
19	-1	-1	1	-1	-1	1	-1	*
20	-1	-1	1	-1	-1	1	1	*
21	-1	-1	1	-1	1	-1	-1	*
22	-1	-1	1	-1	1	-1	1	*
23	-1	-1	1	-1	1	1	-1	*
24	-1	-1	1	-1	1	1	1	*
25	-1	-1	1	1	-1	-1	-1	*
26	-1	-1	1	1	-1	-1	1	*
27	-1	-1	1	1	-1	1	-1	*
28	-1	-1	1	1	1	1	-1	*

The example that I have shown you thus far was for an HSCT aircraft concept. When I performed the screening test, I discovered that 16 variables were required to define the RSE. Within JMP, only an 8 variable RSE can be created. However, there are custom designs created by Dr. Oliver Bandte that can handle up to 16 variables. These designs are face-centered CCDs with a Resolution IV fractional factorial design. These custom DoEs allow for estimates of all main effects as well as all interactions between main effects. This is called a Resolution IV DoE. Then, the fractional factorial designs were merged with a center point in the hyper-cube and a set of face-centered axial points to form the higher than 8 variable CCDs. Regardless, the process to fit the data is the same and I will show you the one for the 16 variable. So, we open up the 16 variable design (which required 289 runs) and insert more columns for our 8 responses and then paste the data from our analysis code.

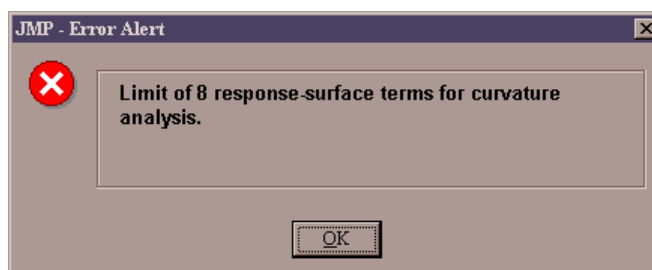
JMP - [HSCT_feasibility_RSE]																								
File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help																								
HSCT_feasibility_RSE																								
HSCT_feasibility																								
	Pattern	Wing_Area	TAV	TIT	FPR	OPR	CLdesign	X2	X3	X4	X5	X6	Y2	tlc_root	tlc_tip	HT_ref	VT_ref	TOGW	TOFL	Vapp	FlyOver	Sideline	Acq \$	
1	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	-1	-1	1	-1	1040939.6	18031	178.2	117.2506055	112.6520525	226.726
2	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	991736.3	16025	173.9	115.3133015	111.9433999	218.465	
3	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1	-1	-1	-1	-1	989833.6	14384	173.8	111.406949	112.007792	223.968	
4	-----	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	1001216.1	15976	174.8	114.4137863	112.0477577	218.185	
5	-----	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	1	1	1	1	-1	1038616.1	16181	178	115.6574668	112.5664653	222.026	
6	-----	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	1	1	-1	-1	-1	-1	884960.1	13834	164.3	112.6956837	110.594171	210.871	
7	-----	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1	-1	-1	-1	1	1	997338.2	13817	174.4	112.1387354	112.068204	220.68	
8	-----	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	-1	-1	-1	-1	-1	944985.5	16284	169.8	114.4635931	111.3485357	216.374	
9	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	1	1116752.4	17299	184.6	115.4729394	113.73263	232.81	
10	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1	-1	-1	-1	-1	905814.9	14302	166.2	111.9125598	110.7956309	211.067	
11	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	1002940.2	14861	174.9	114.1514105	112.0723956	222.31	
12	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	-1	-1	933711.7	15766	168.8	115.8440086	111.3692686	211.964	
13	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	1	1	-1	-1	926209.4	14642	168.1	111.4075603	111.0610536	212.446	
14	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	917866.3	14002	167.3	111.6836366	110.9483936	213.202	
15	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1	1	1	-1	-1	891592.1	13688	164.9	110.6805303	110.6188296	210.261	
16	-----	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1	987376.5	15816	173.6	115.5153615	111.8997605	219.112	
17	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	955427.3	15031	170.7	112.179814	111.4484707	214.994	
18	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	967454.4	14707	171.8	112.5106025	111.6077833	217.445	
19	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	1	931240.4	13940	168.5	111.3167338	111.1387704	213.388	
20	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	-1	1015649.7	17337	176	116.9670761	112.3270218	221.136	
21	-----	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	1080174	16762	181.5	114.3624053	113.2144481	228.55	

Now, let's create the RSEs! Consider the example JMP file below. There are 8 responses and 16 design variables. Again, go to **Analyze** and **Fit Model**. Highlight your variables and instead of clicking the **Add** button as you did for the screening test, you want to click **Macros**. A drop menu will appear. Select the **Response Surface** option. The white area under the "Construct Model Effects" will fill out with the coefficients for a second order RSE that JMP will be solving for in the regression. Then, select your responses and put them in the **Y** area again. DON'T FORGET TO UNSELECT THE CENTER POLYNOMIALS OPTION UNDER MODEL SPECIFICATION!

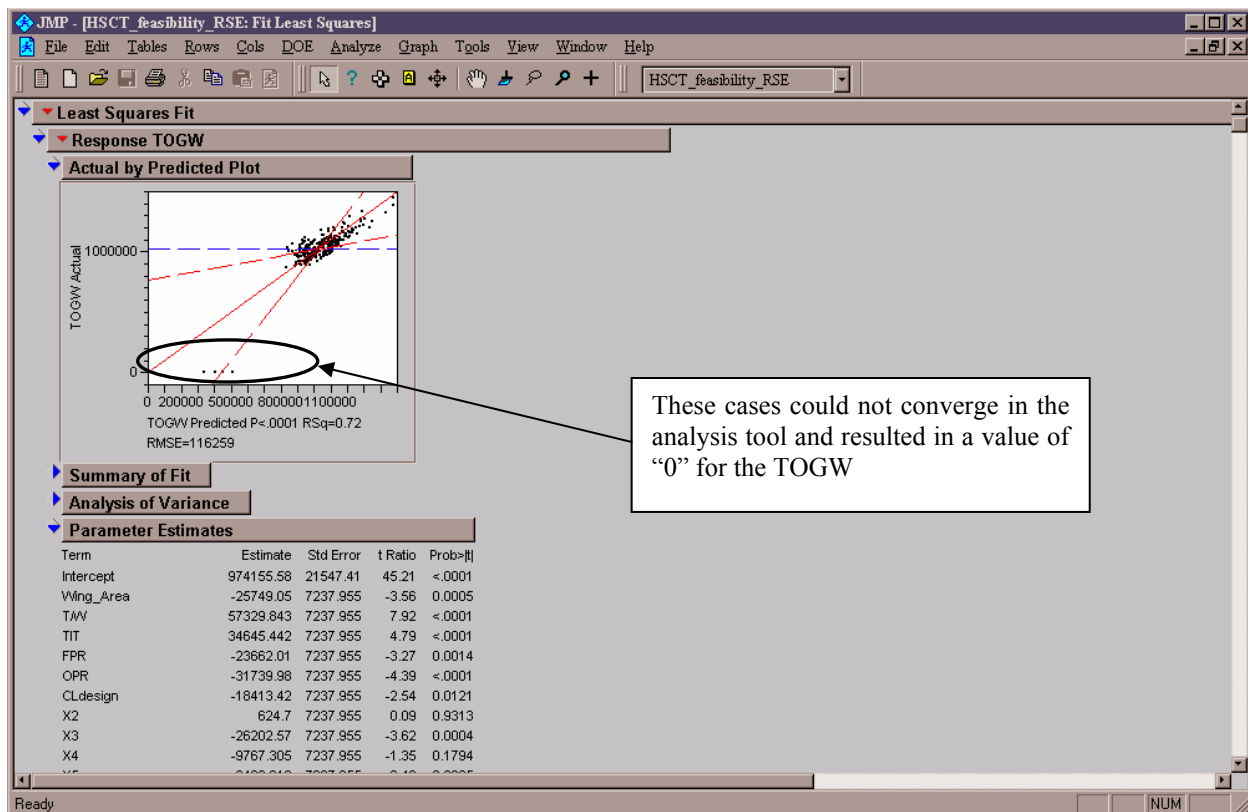
One thing before you proceed: in the “Construct Model Effects”, you have your “to be determined” coefficients. Highlight all of the main effect variables that have the symbol “&RS” by them. Then click the **Attributes** drop menu and unselect the “Response Surface Effect”. The reason for this is that JMP only likes to have 8 variables and just gives you a warning when you fit the model. Doing what you just did suppresses the annoying little error. This does not affect the fit of the model at all. Once you have done this then hit **Run Model**.



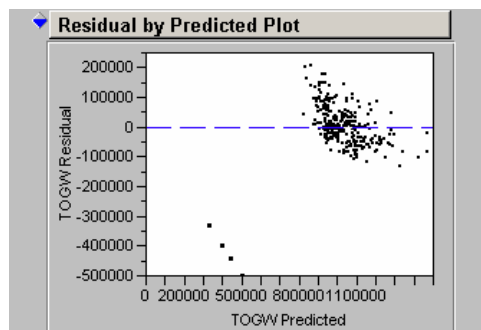
Oh, this is the little error window you would get if you didn't de-select the Attributes.



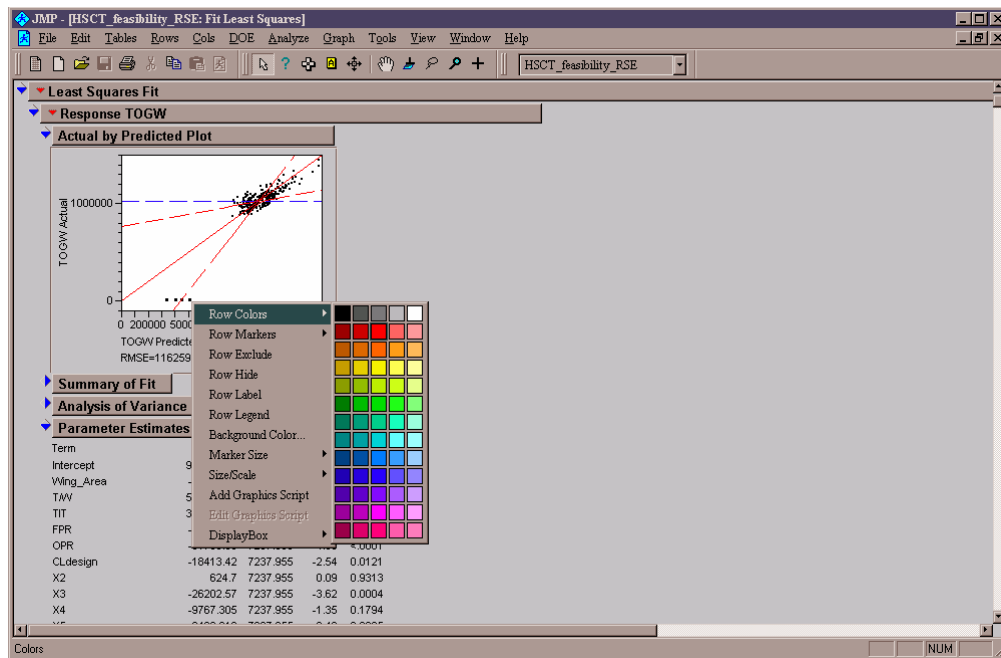
When JMP is finished fitting the model, similar windows will pop up as they did in the screening test. I want you to note some differences here. Look at the error bars (the dotted red lines) around the perfect model fit and compare those to the ones you saw in the screening test earlier. Note the HUGE spread. One would think that the original linear fit was better, but look at the 4 cases that are on the bottom. These cases actually did not converge in the analysis program. The particular combination of variable settings inhibited the program from converging. Thus, the values of “0” for each of the responses will mess up the model. There are a couple of solutions. First, go back to the DoE table and determine which variables might be affecting the failure. You do this by looking at the rows before and after the failed case and determine which combination of the variable settings is causing the program to fail. Then, you can modify the ranges and re-execute another DoE if there are too many failed cases. Another option is at your disposal, **ONLY IF YOU HAVE A FEW FAILED CASES**. Maybe a good rule of thumb is that you can exclude only 2-3% of the total cases you executed before you should modify the ranges or the DoE that you ran. For 289 cases considered herein, I am going to “Exclude” these 4 failed cases from the model and allow a regression on the remaining 285 cases.



If you look at the Residual Plot below you can see that there is a clumping of responses. Also, the Y-axis scale is one-third the size of the X-axis. This implies very large residuals and a poor fit. The Y-axis should be less than one tenth of the X-axis for residuals to be considered reasonable. It is important to examine the scale as well as the shape.



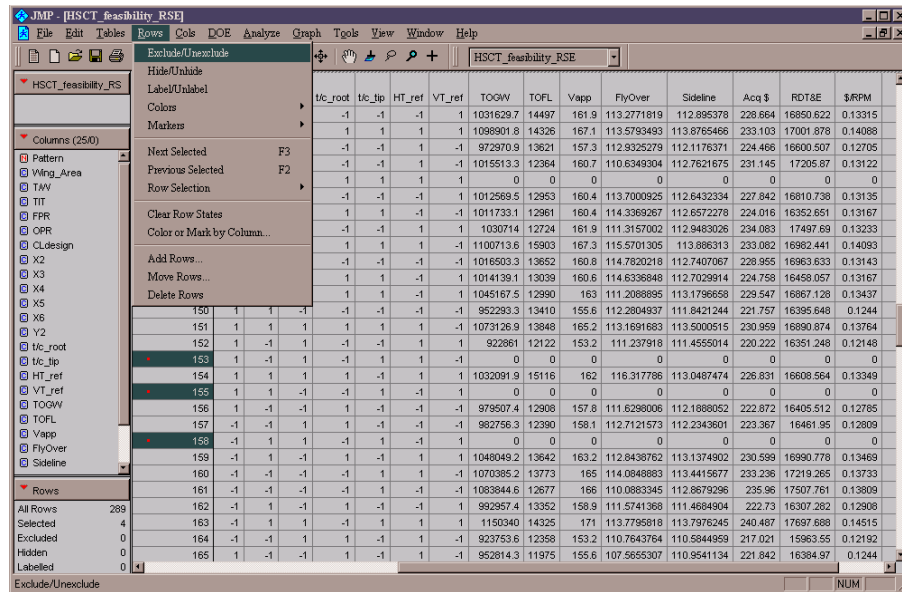
To do this, put your mouse over one of the four dots in the “Actual by Predicted Plot” above and left mouse click one of them. You will see that the little dot gets bigger. Then hold down the shift key and click another, and another and another. Now, right mouse click and the window below will pop up. Select the **Row Colors** option and then pick one of the colors, say red. You will see that the 4 dots that you selected are now red.




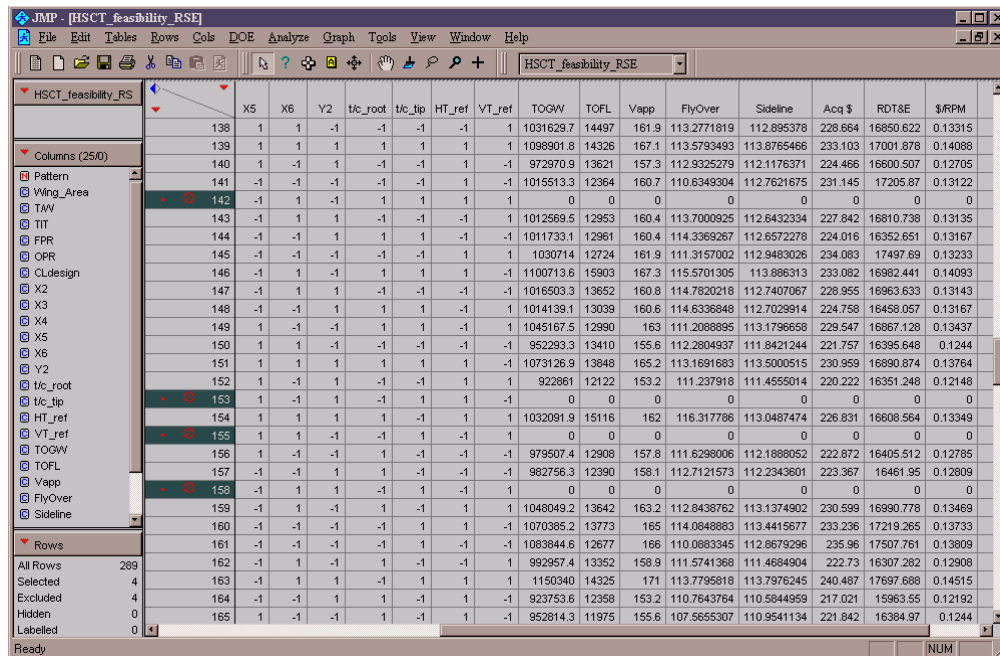
Go back to the DoE table window and scroll down until you find the highlighted rows that have little red dots beside them as shown below.

	X5	X6	Y2	t/c_root	t/c_tip	HT_ref	VT_ref	TOGW	TOFL	Vapp	FlyOver	Sideline	Acq \$	RDT&E	\$RPM
138	1	1	-1	-1	-1	-1	1	1031629.7	14497	161.9	113.2771819	112.895378	228.664	16850.622	0.13315
139	1	1	1	1	1	1	1	1098901.8	14326	167.1	113.5793493	113.8765466	233.103	17001.878	0.14088
140	1	-1	1	-1	-1	1	-1	972970.9	13621	157.3	112.9325279	112.1176371	224.466	16600.507	0.12705
141	-1	-1	-1	-1	-1	1	-1	1015513.3	12364	160.7	110.6349304	112.7621675	231.145	17205.87	0.13122
142	-1	1	-1	1	1	1	1	0	0	0	0	0	0	0	0
143	-1	1	1	-1	-1	-1	1	1012569.5	12953	160.4	113.7000925	112.6432334	227.842	16810.738	0.13135
144	-1	-1	1	1	1	1	-1	1011733.1	12961	160.4	114.3369267	112.6572278	224.016	16352.651	0.13167
145	-1	-1	-1	-1	-1	1	1	1030714	12724	161.9	111.3157002	112.9483026	234.083	17497.69	0.13233
146	-1	1	-1	1	1	1	-1	1100713.6	15903	167.3	115.5701305	113.886313	233.082	16982.441	0.14093
147	-1	1	1	-1	1	-1	-1	1016503.3	13652	160.8	114.7820218	112.7407067	228.955	16963.633	0.13143
148	-1	-1	1	1	1	-1	1	1014139.1	13039	160.6	114.6336848	112.7029914	224.758	16458.057	0.13167
149	1	-1	-1	1	1	-1	-1	1045167.5	12990	163	111.2088895	113.1796658	229.547	16667.128	0.13437
150	1	1	-1	-1	-1	-1	-1	952293.3	13410	155.6	112.2804937	111.8421244	221.757	16395.648	0.1244
151	1	1	1	1	1	1	-1	1073126.9	13848	165.2	113.1691683	113.5000515	230.959	16890.874	0.13764
152	1	-1	1	-1	-1	1	1	922861	12122	153.2	111.237918	111.4555014	220.222	16351.248	0.12148
153	1	-1	1	-1	1	1	-1	0	0	0	0	0	0	0	0
154	1	1	1	1	-1	-1	1	1032091.9	15116	162	116.317786	113.0487474	226.831	16608.564	0.13349
155	1	1	-1	-1	-1	-1	1	0	0	0	0	0	0	0	0
156	1	-1	-1	1	-1	-1	-1	979507.4	12908	157.8	111.6298006	112.1888052	222.872	16405.512	0.12785
157	-1	-1	1	1	1	-1	-1	982756.3	12390	158.1	112.7121573	112.2343601	223.367	16461.95	0.12809
158	-1	1	1	-1	-1	-1	1	0	0	0	0	0	0	0	0
159	-1	1	-1	1	-1	1	1	1048049.2	13642	163.2	112.8438762	113.1374902	230.599	16990.778	0.13469
160	-1	-1	-1	-1	-1	1	1	1070385.2	13773	165	114.0848883	113.4415677	233.236	17219.265	0.13733
161	-1	-1	-1	-1	1	-1	-1	1083844.6	12677	166	110.0883345	112.8679296	235.96	17507.761	0.13809
162	-1	1	-1	1	-1	-1	1	992957.4	13352	158.9	111.5741368	111.4684904	222.73	16307.282	0.12908
163	-1	1	1	-1	-1	1	1	1150340	14325	171	113.7795818	113.7976245	240.487	17697.688	0.14515
164	-1	-1	1	1	-1	-1	-1	923753.6	12358	153.2	110.7643764	110.5844959	217.021	15963.55	0.12192
165	1	-1	-1	1	-1	1	-1	952814.3	11975	155.6	107.5655307	110.9541134	221.842	16384.97	0.1244

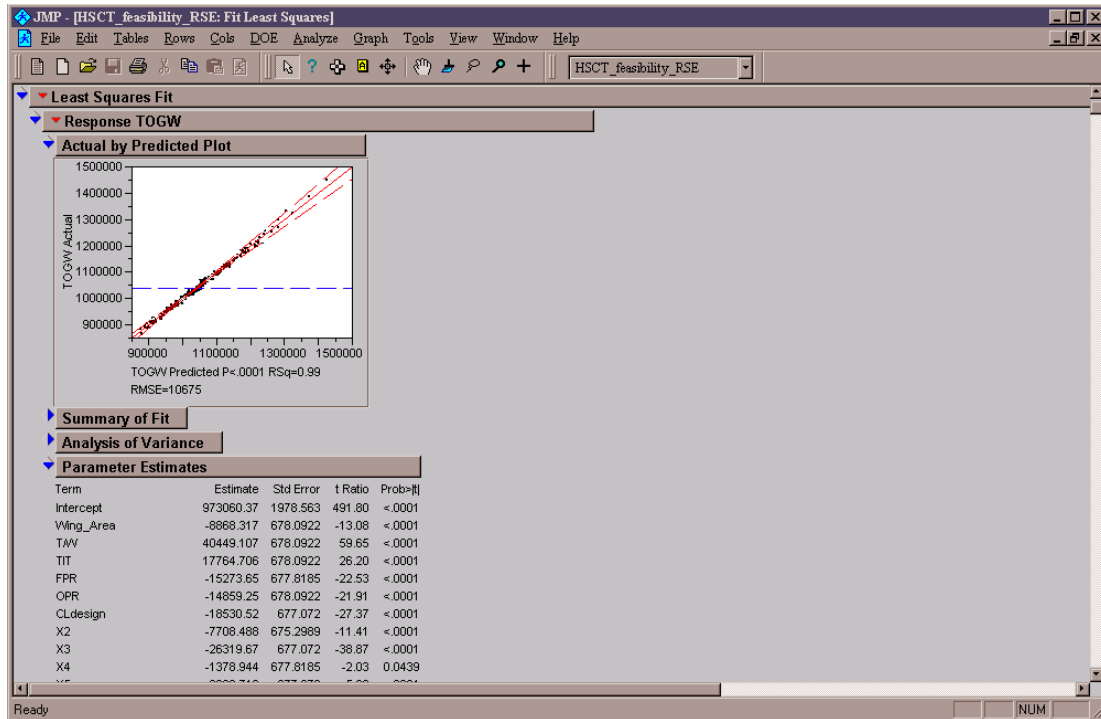
We want to exclude these 4 cases from the analysis, so, go under **Rows** and select the “Exclude/Unexclude” option.



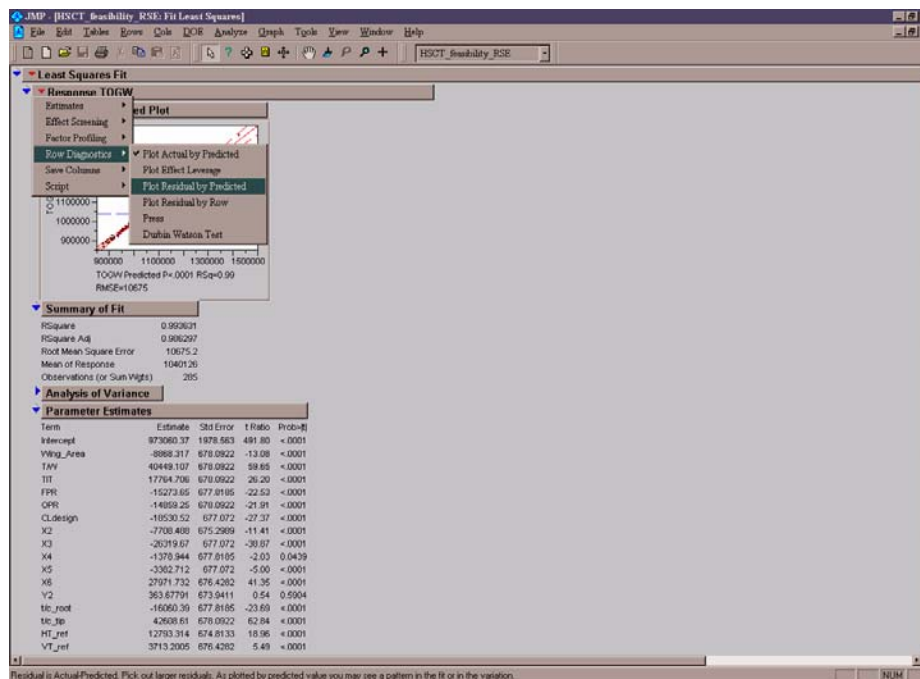
JMP will add  by each row. This means that these rows will be excluded from the model. You will lose some degrees of freedom, but if you only eliminate a few cases, you should be ok. Please look at any DoE or Response Surface book or the JMP Help menu for more information about degrees of freedom. Now go through the same process as above regarding fitting the model.



Now when we get our new window that has the “Actual by Predicted”, look at the significant difference in the error bars. They are much tighter! For a good “Actual by Predicted”, you want to have each of the dots (or cases) to be as close to the diagonal line as possible. The diagonal represents the perfect fit. AS the dots (or cases) move away from the diagonal, the error in the prediction increases. The red dashed lines around the diagonal represent the 95% confidence intervals of the prediction and the blue horizontal dashed line represents the mean of the response. If by chance the blue dashed line falls inside the red dashed lines, you have a VERY bad fit.

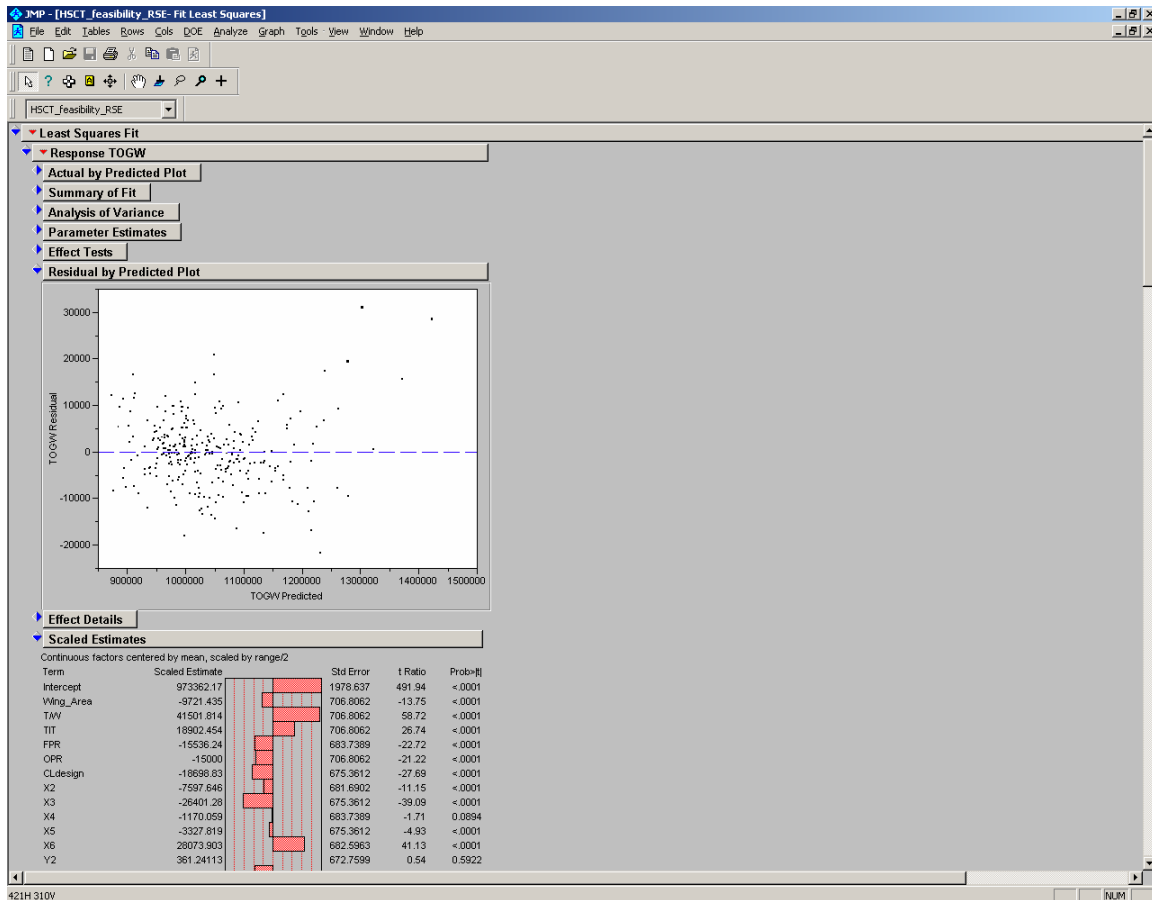


For another check of you model, go to the little red ▼ by the “Response TOGW” drop menu and click on **Row Diagnostics** and then select “Plot Residual by Predicted” option as shown below.

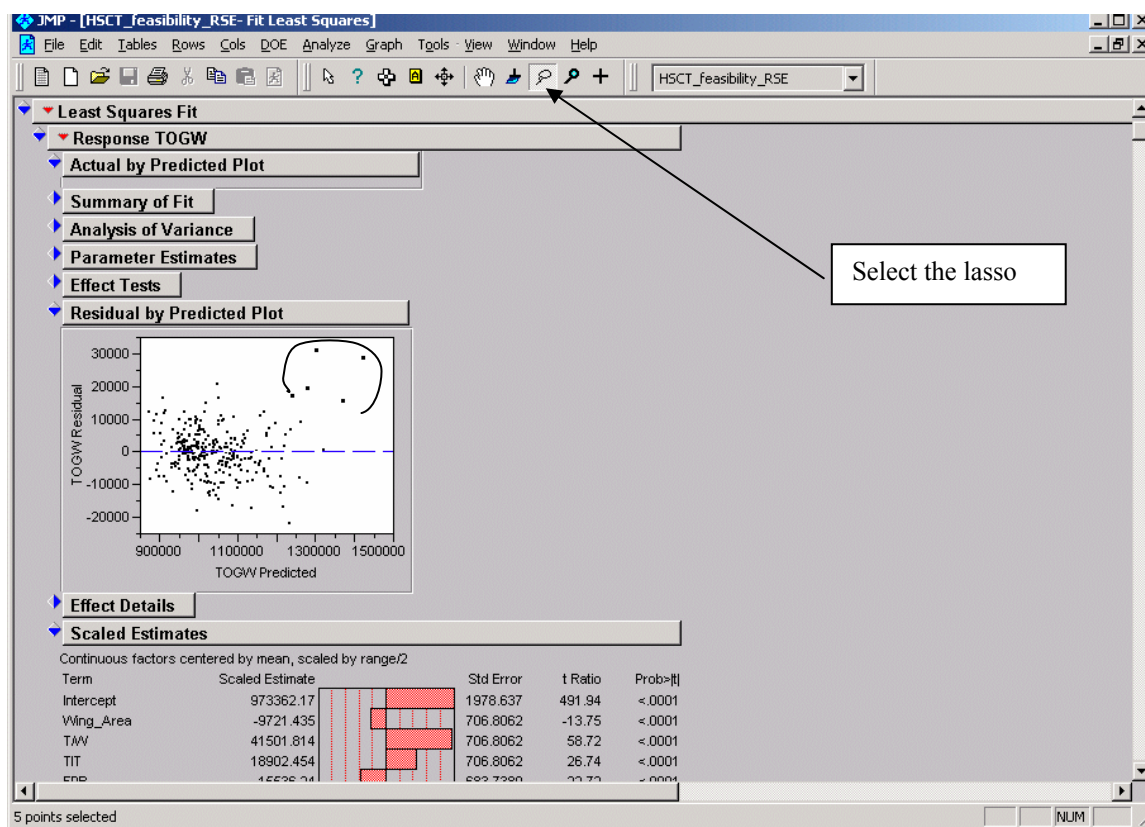


Then scroll down until you see the Residual plot. This plot is also called a “scatter plot”. The residual is the error in the fitted model and is the difference between the actual value of each observation and the value predicted by the fitted model. You typically want a nice *random shotgun scatter of your error with a very small magnitude* on the vertical scale with respect to the predicted values. The example below isn’t too bad. There are only a few points at the top that stand out as having high error. For only a few cases like this, you could simply exclude those from your model and refit. However, you should look at the particular cases and try to determine if there is a pattern of variable combinations that are inducing an error. If so, you might want to investigate your analysis code to determine if there is a modeling problem.

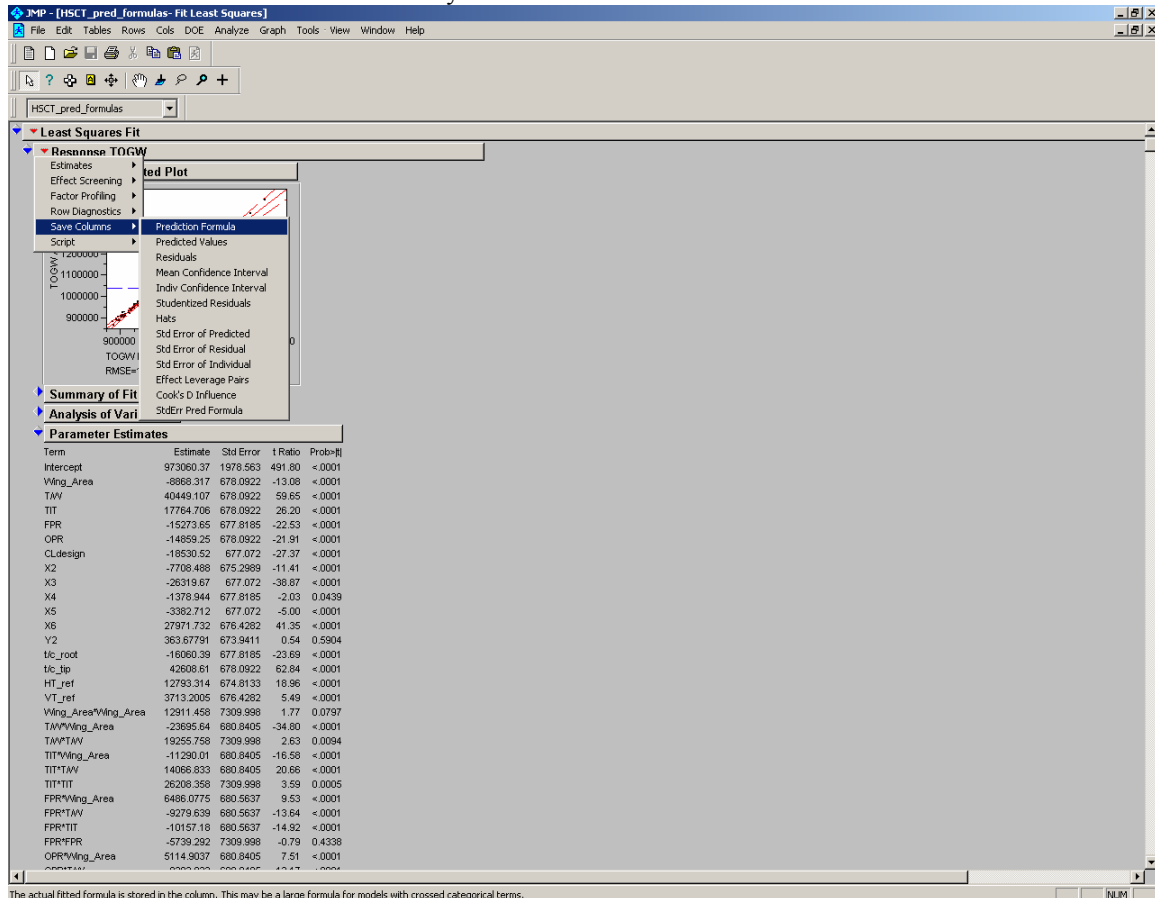
Also, if there is a pattern to the residual (i.e., looks like a smiley face or a sine wave), a couple of things may be going on: 1) you may need a transformation of your dependent variables to get a random gunshot, or 2) you may need higher order effects of your model.



There are two ways to select the dots on the Residual plot. The first is to simply click on each dot individually. Another is to go up on the top menu and select the little lasso icon. Then draw a circle around the cases that are outliers by holding down the left mouse button and drawing the circle to “lasso the cases”! Then you can highlight them as you did before and identify the cases from the DoE table. For this example, excluding the 4 cases above helped the fit sufficiently that we can proceed.



There is an assumption that a second order model will fit the data and that the higher order terms clump into an error term with normal distribution. The foundation for this is that you are fitting a model based on a Taylor Series expansion. For a second order model, you assume that all higher order effects are negligible and can be lumped into an error term. For this assumption to be valid, that error term usually needs to be a standard normal distribution with a mean of 0 and a standard deviation of 1. Checking this error distribution is a good way of determining if you have a good fit with the RSE. If the distribution is not normal, it implies that the model you fit is not good, you may have bad cases or you may need a transformation of inclusion of higher order effects. To find the percent error and the error distribution, you must save the predicted formulas. Under the little red ▼ by Response TOGW, select **Save Columns**, then **Prediction Formula**. This will add a row to your DoE table called “Pred Formula TOGW”.

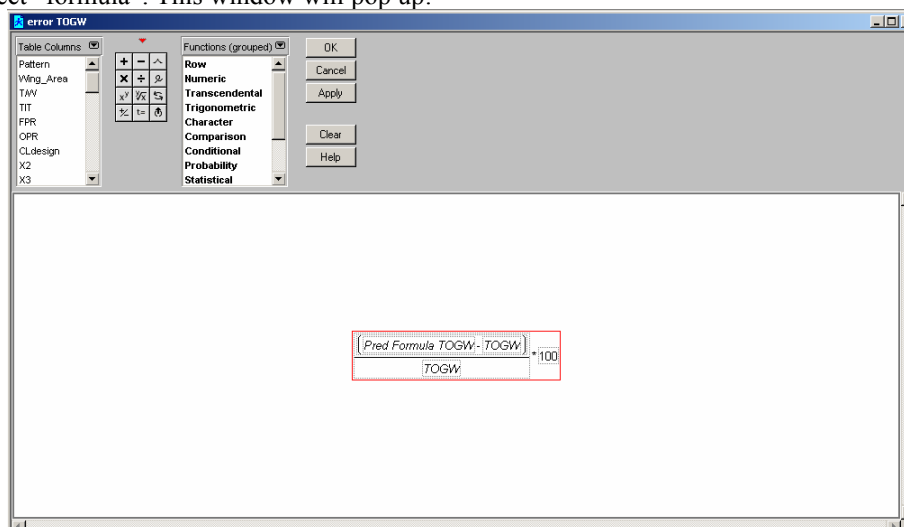


The actual fitted formula is stored in the column. This may be a large formula for models with crossed categorical terms.

Repeat this for every response so your data table looks like this:

	Acq \$	RD&E	\$RPM	Pred Formula TOGW	Pred Formula TOFL	Pred Formula Vapp	Pred Formula FlyOver	Pred Formula Slatline	Pred Formula Acq \$	Pred Formula RD&E	Pred Formula \$RPM
1	226.726	16533.367	0.13428	1037671.55	17848.3842	177.805498	116.969206	112.660097	226.311096	16515.631	0.13393736
2	218.469	15766.52	0.12951	996543.756	18140.4218	174.255458	115.303305	112.041214	219.074976	15811.5169	0.13004075
3	223.966	16516.909	0.12863	980010.778	14356.3112	172.931356	111.212599	111.845598	223.204892	16454.9819	0.12767393
4	218.165	15703.406	0.13121	998637.167	15835.6667	174.616299	114.31219	112.012317	217.855532	15681.6419	0.13084276
5	222.026	15991.163	0.1346	1037256.73	16287.8524	177.760896	115.520774	112.551681	221.742929	15970.109	0.13468993
6	210.871	15398.187	0.1181	872775.002	13767.5301	163.457751	112.624649	110.391944	209.756071	15326.2343	0.11678795
7	220.68	16032.323	0.13042	996120.039	13923.6607	174.206915	112.053931	112.074335	220.622879	16032.9838	0.12996888
8	216.374	15745.416	0.12431	950160.77	16037.4095	170.201757	114.379978	111.454513	217.124659	15802.7563	0.12489746
9	232.81	16920.571	0.14261	1125893.07	17363.0515	185.285491	115.511855	113.859843	233.718743	16979.9653	0.14363062
10	211.067	15302.946	0.12084	903644.617	14443.7741	165.95008	111.839167	110.773405	210.821423	15280.4327	0.12055319
11	222.31	16198.352	0.13083	999919.235	14710.0505	174.882619	114.438146	111.980684	221.970157	16175.6309	0.13052394
12	211.964	15293.313	0.12363	937274.321	15794.1753	169.03895	115.905913	111.41708	212.154581	15306.432	0.12411463
13	212.446	15407.237	0.12276	929816.468	14557.6903	168.464801	111.674216	111.08941	212.758018	15430.4581	0.12307785
14	213.202	15527.064	0.12188	918613.321	13786.9545	167.498658	111.883373	110.924968	213.3424	15536.7267	0.12187023
15	210.261	15272.899	0.11885	895149.183	13701.279	165.213986	110.806391	110.647055	210.549671	15290.3372	0.11933241
16	219.112	15868.962	0.129	994384.95	16330.1987	174.165089	115.592358	112.031581	219.632426	15896.5659	0.12967002
17	214.994	15538.793	0.12614	950968.174	14986.4836	170.574243	112.480586	111.33634	214.585695	15510.4715	0.12565139
18	217.449	15784.445	0.12703	972615.896	14796.8032	172.322142	112.665542	111.667433	217.846177	15813.1172	0.12749377
19	213.388	15477.673	0.12308	930012.549	13745.8847	168.477755	111.354843	111.113585	213.347586	15460.9147	0.12317751

Now you want to find the percent error between the actual and the predicted responses. Add columns with **Cols, Add Multiple Columns**, and add eight columns after the last column. Rename the first column 'error TOGW'. Each column will find the percent error for one response, so name them appropriately. Right click on the first of the columns and select "formula". This window will pop up:



Enter the formula for percent error using the column names:

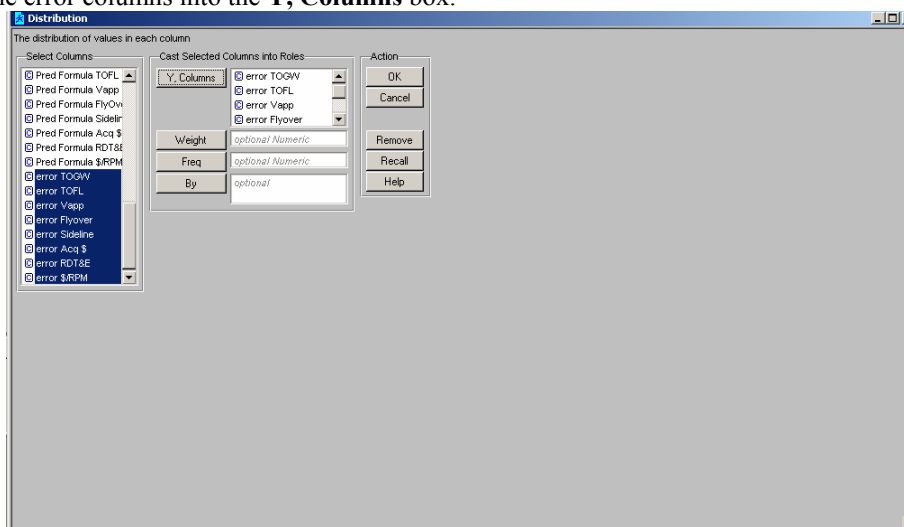
$$\text{Percent error} = (\text{Predicted Value} - \text{Actual Value}) / \text{Actual Value} * 100$$

NOTE: JMP does not like number entered first into the formula. If you are multiplying by a constant, do so at the end of the formula.

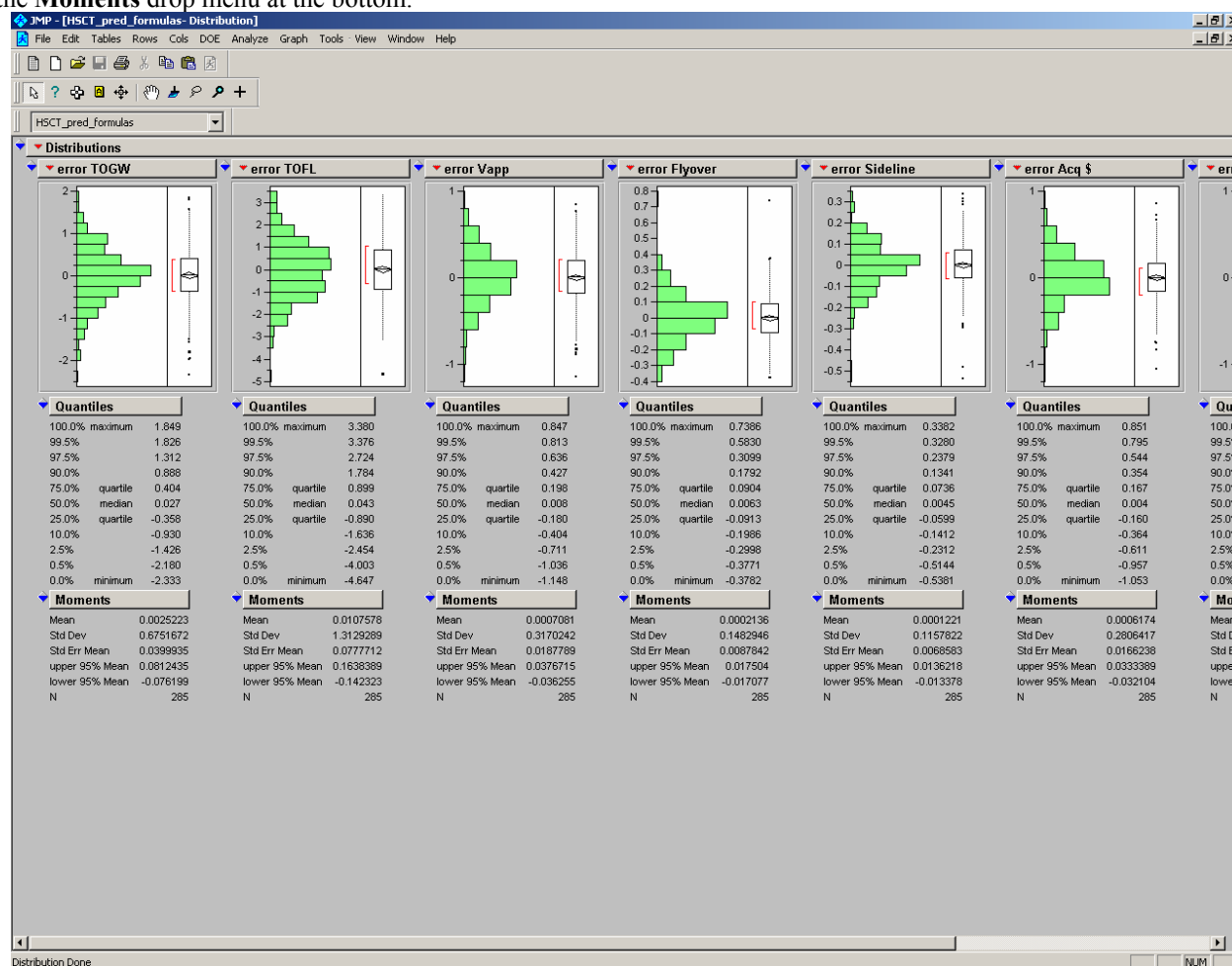
After the percent error for each response has been calculated using the entered formula, you want to see if the distribution is normal. Go to **Analyze, Distribution**.

	Pred Formula Acq \$	Pred Formula RDT&E	Pred Formula \$RPM	error TOGW	error TOFL	error Vapp	error Flyover	error Sideline	error Acq \$	error RDT&E	error \$RPM
1	226.311096	16515.631	0.13393736	-0.31395	-1.01279	-0.22138	-0.24	0.000071	-0.183	-0.10727	-0.25517
2	219.074976	15811.5169	0.13004075	0.484751	0.720261	0.204403	-0.00867	0.000874	0.277374	0.265395	0.409811
3	223.204992	16454.9819	0.12767393	-0.99237	-0.1925	-0.4998	-0.17445	-0.00145	-0.33983	-0.37493	-0.74327
4	219.012317	217.855532	15681.8419	0.13084278	-0.25758	-0.8784	-0.10509	-0.0888	-0.00032	-0.14185	-0.13859
5	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
6	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
7	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
8	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
9	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
10	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
11	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
12	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
13	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
14	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
15	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
16	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
17	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
18	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
19	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
20	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
21	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
22	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
23	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
24	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
25	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
26	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
27	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
28	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
29	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
30	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
31	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
32	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
33	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
34	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
35	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
36	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
37	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
38	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
39	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
40	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166
41	112.01317	221.742329	15870.109	0.13468993	-0.13088	0.660357	-0.13433	-0.11819	-0.00013	-0.12749	-0.13166

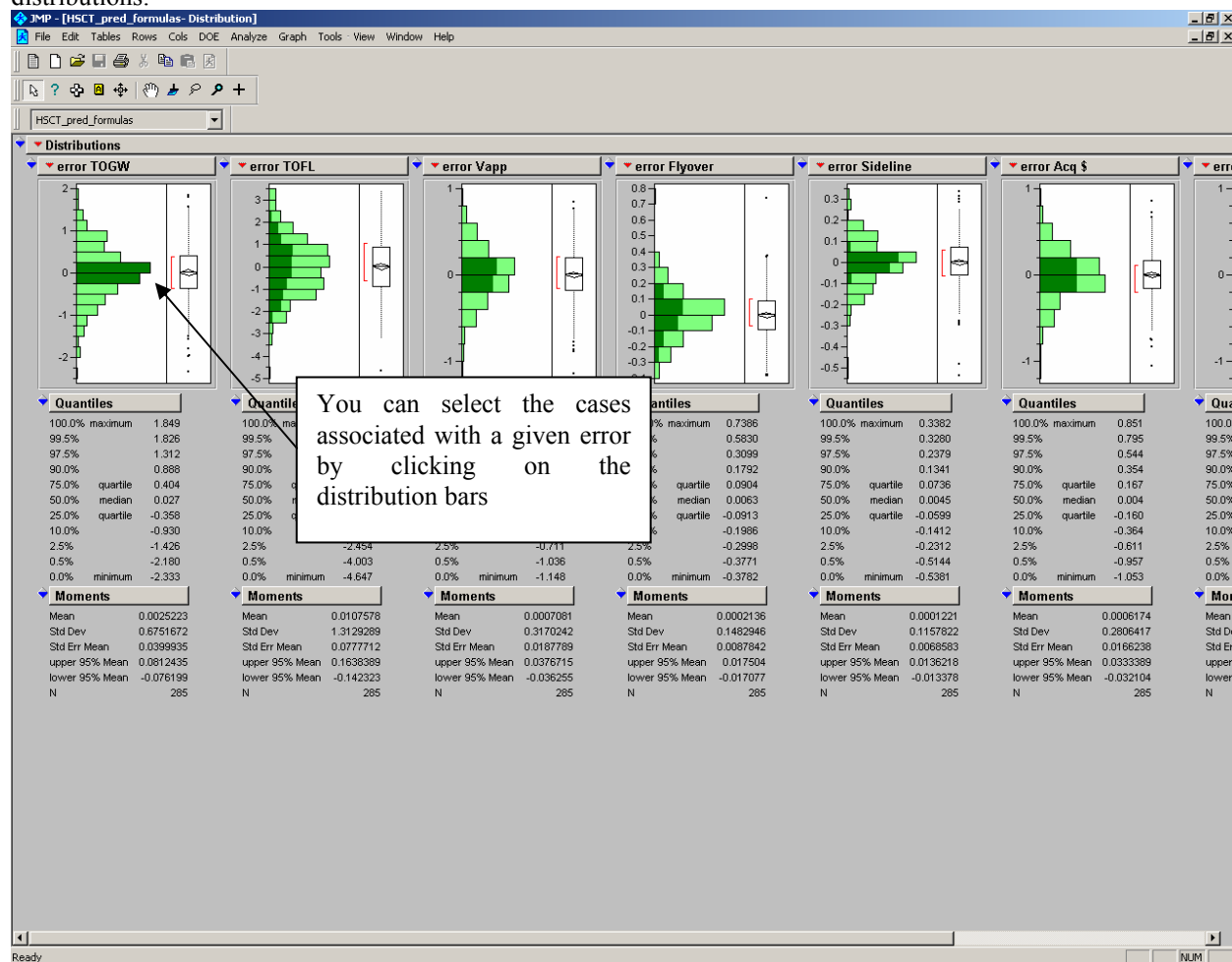
Place the error columns into the **Y, Columns** box.



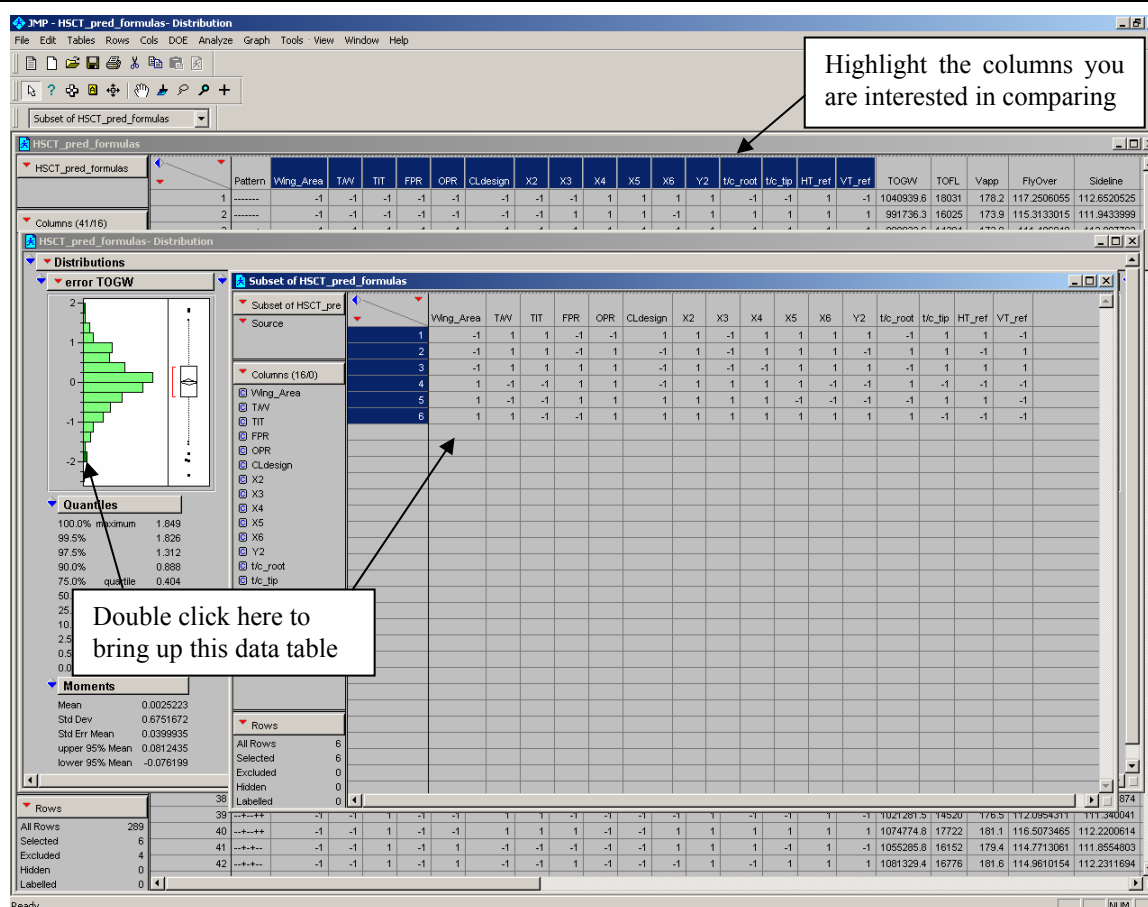
The distribution for the error will pop up. This gives you a distribution, a box plot, quantiles, and moments about each column. Here you can check for normal distribution with a mean of 0 and a standard deviation of 1 under the **Moments** drop menu at the bottom.



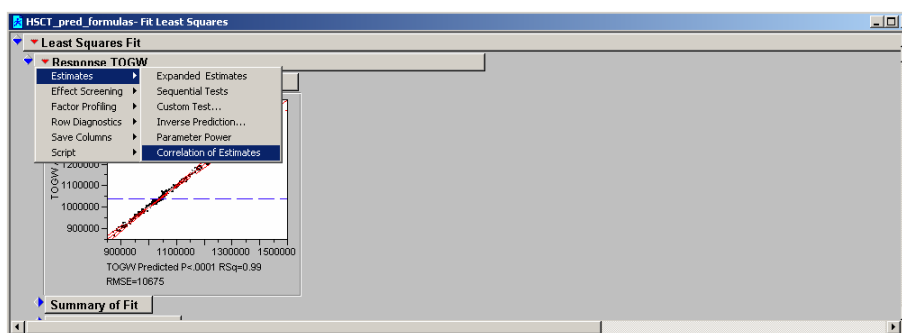
If the distributions are not normal you have three options: exclude cases, transform the responses with logarithmic or exponential functions, or include higher order effects. For this tutorial, we will focus on excluding cases. To select cases to exclude, you can click on the distributions or the box plots. Selecting a bar of the distribution selects all the cases within that bar. If you only want to select some of the cases within a bar, use control and the left mouse button to scroll the axis or zoom in with the magnifier in the tool bar. An interesting aspect of these distributions is that selecting a case in one selects it in all of them so you can see where the cases fall throughout all the distributions.



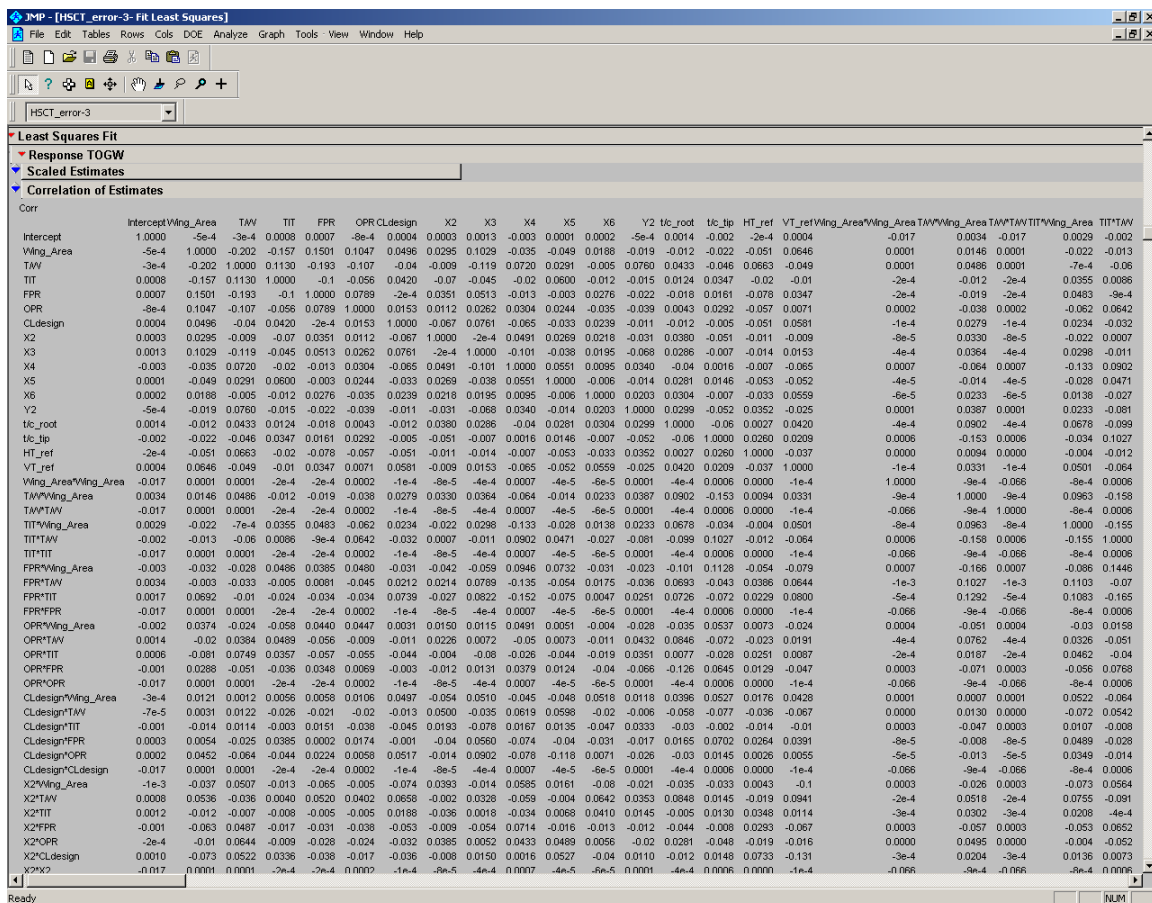
You want to exclude cases that have large percent errors to improve the fit of your RSEs. After selecting the cases you wish to exclude, it is a good idea to check if there is a pattern to those cases. In the DoE table, select the columns you want to compare by highlighting the name row. Go back to the distributions and double click on any of the selected points. This will bring up a table containing the information for those points. This is an easy way to find patterns and see if anything specific is causing the large error.



With the cases you want to exclude selected, go back to the data table and try excluding these. Rerun the analysis. You have to be careful how many cases are excluded. One way to judge if you have excluded too many cases is to look at the Correlation of Estimates.

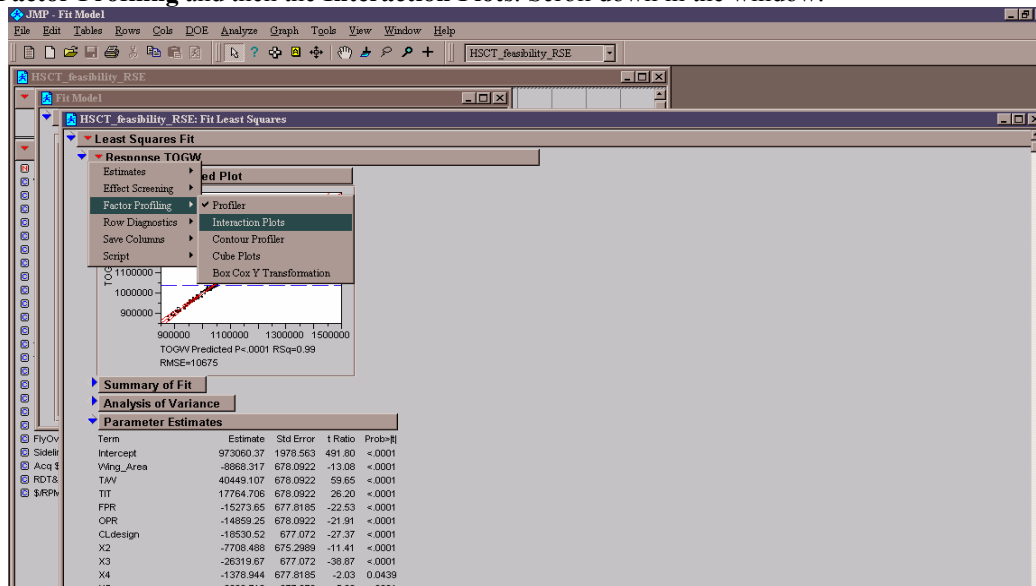


The Correlation of Estimates is a symmetric matrix that shows the mathematical correlation between the coefficient estimates. You should check that these numbers, except for the “1”s that make up the diagonal, are below ± 0.15 . If any number in this matrix exceeds ± 0.25 , you will not be able to differentiate between the influences of those coefficient estimates due to the prediction being correlated. What this implies is that if you are trying to estimate the coefficient for one term in your RSE and it has a high correlation with another coefficient, you will not be able to distinguish which of those coefficients is actually contributing to the response. This means you have excluded too many cases from your DoE and you cannot estimate your responses with your current data set and DoE. Check this matrix for each response when you exclude more than 5% of your original DoE cases. If your correlations start getting high, you need to modify your DoE by changing ranges, transforming your data, and/or check your analysis tool to see if you set up your model correctly.

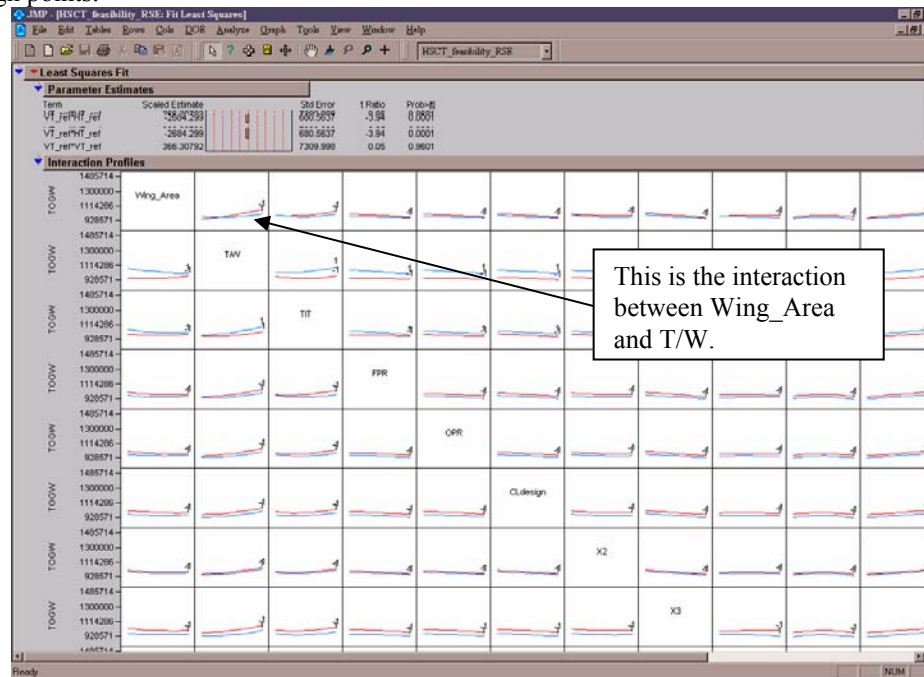


Looking at your actual versus predicted plot and the residuals plot, the fit of these two plots should reflect a better fit through the remaining cases.

The most accurate means of determining how well your RSEs model your analysis code is to run a set of random cases. This is especially important if your responses are highly quadratic and there are very strong interactions amongst variables. To establish the interactions between variables, go to the red arrow beside “Response TOGW” and select the **Factor Profiling** and then the **Interaction Plots**. Scroll down in the window.

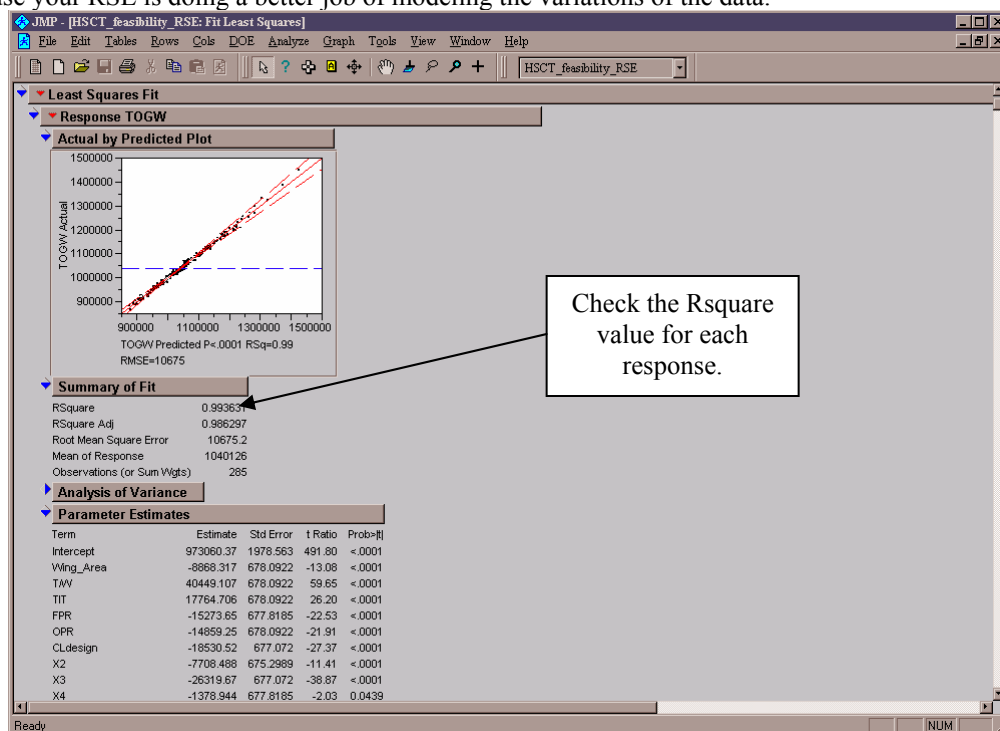


The plot below will come up. To identify if there are strong interactions between variables, look at one of the boxes. For example, consider the interaction between Wing_area and T/W. If these two variables had a small interaction between each other, the two lines that you see would be parallel. However, when interactions exist, the lines will have different slopes. Very strong interactions can be identified when one line crosses the other. What happens within the RSE for cases like this is that one effect can be masked by the other and when you evaluate your RSEs at values other than the cases used to create the RSEs, you may have significant prediction errors. However, if the interactions between variables are small and your responses are not extremely quadratic, your RSEs should behave well at off design points.

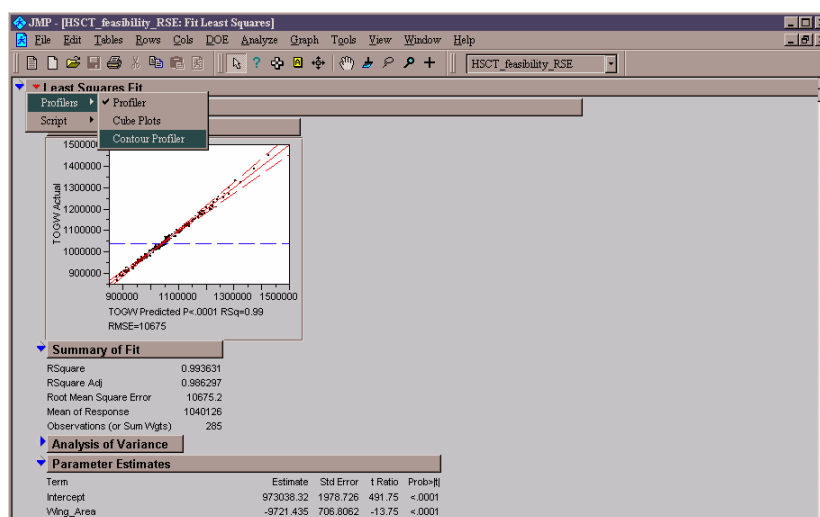


However, if you do have strong interactions and highly quadratic responses, you need to run a set of random cases. Especially if you don't know a priori the behavior of a response. The suggested amount of random cases is an equivalent amount to the number of cases you ran for the original DoE. You can do this by randomly picking values between "-1" and "1" and creating a new DoE table. You can do this in Excel in your convert spreadsheet using the formula $=2*\text{rand}() - 1$. This will give you a value between -1 and 1. You will want to paste special these numbers as values into the convert sheet because they have a tendency to change with any change in the spreadsheet. Re-execute your analysis tool for those random cases to get your "Actual Response Values". Bring the responses into the DoE with the newest prediction formulas calculated after excluding cases and save as a new file. Bring in the random values, which will automatically update the values in the predicted formulas and the error columns. Now you can look at the error distribution to see how the RSE performs at off design points, again look for a normal distribution. An acceptable level of error is $\pm 5\%$. If your error is higher than this, you should re-examine your ranges and the DoE that you used. For a given design problem, this effort should be done at least once to get a feel for how well a 2nd order RSE can capture a given response. This is a valuable one-time investment.

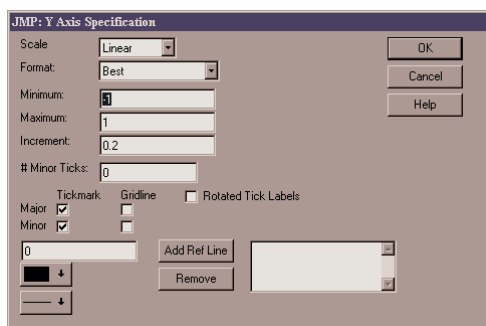
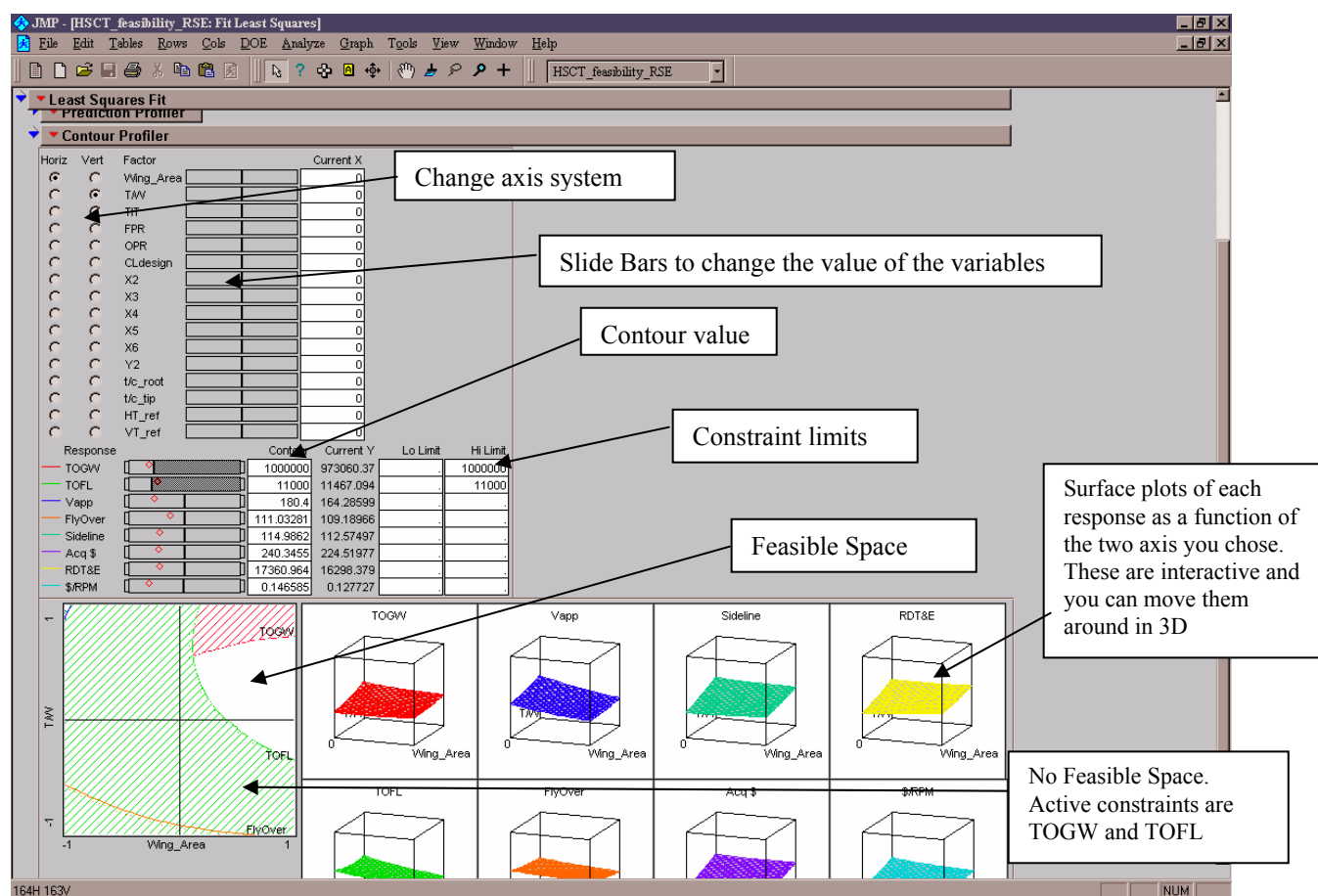
For one last test to see how well the RSE is predicting your analysis code, click the **Summary of Fit** button and observe the “Rsquare” value. Rsquare is a number that indicates the accuracy of your predicted graph. A value of one indicates that the relationship is perfect, while zero indicates no relationship whatsoever. As you can see it has a value of 0.993631. This means that the second order DoE model that you chose explains over 99% of the variation in the data. With this check for the goodness of the fit of your model, you typically want a value greater than 90%. However, the R^2 value IS NOT THE ONLY CHECK FOR THE GOODNESS OF FIT! The R^2 tells you how well you are predicting the responses at the values prescribed by your DoE table. It DOES NOT tell you how accurate your responses will be at variable settings other than “-1”, “0”, or “1”. This value will be closer to one if you have excluded cases, because your RSE is doing a better job of modeling the variations of the data.



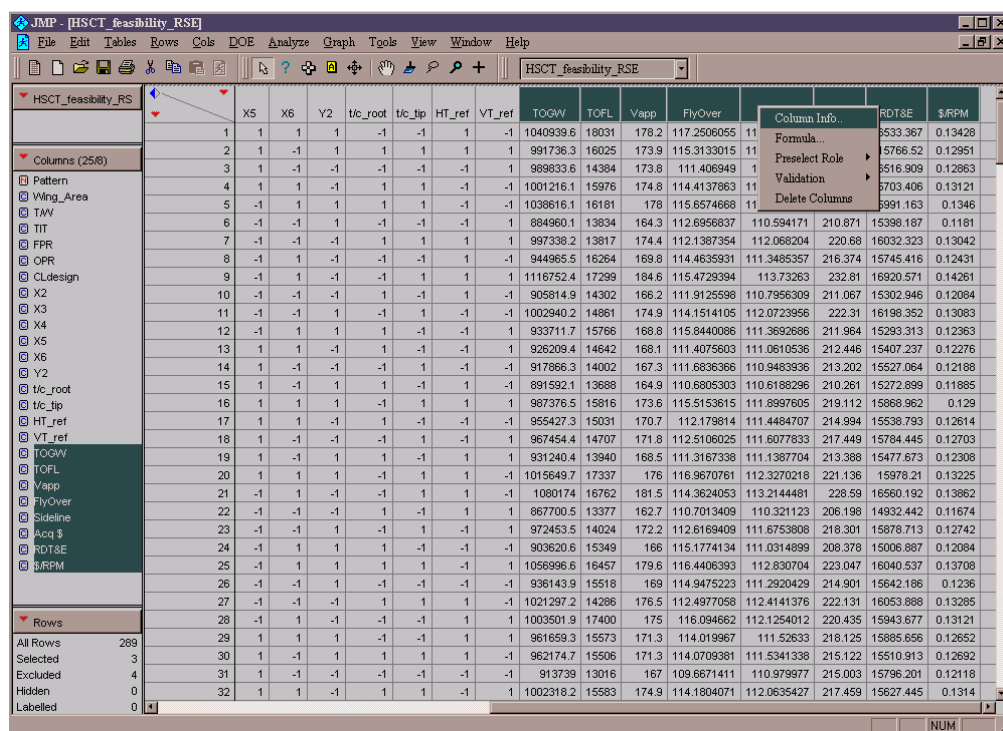
Another great feature of JMP is the ability to see contour plots. So, go under the **Least Squares Fit** drop menu again and select the **Profiler** option again, but now select the “Contour Profiler” option.



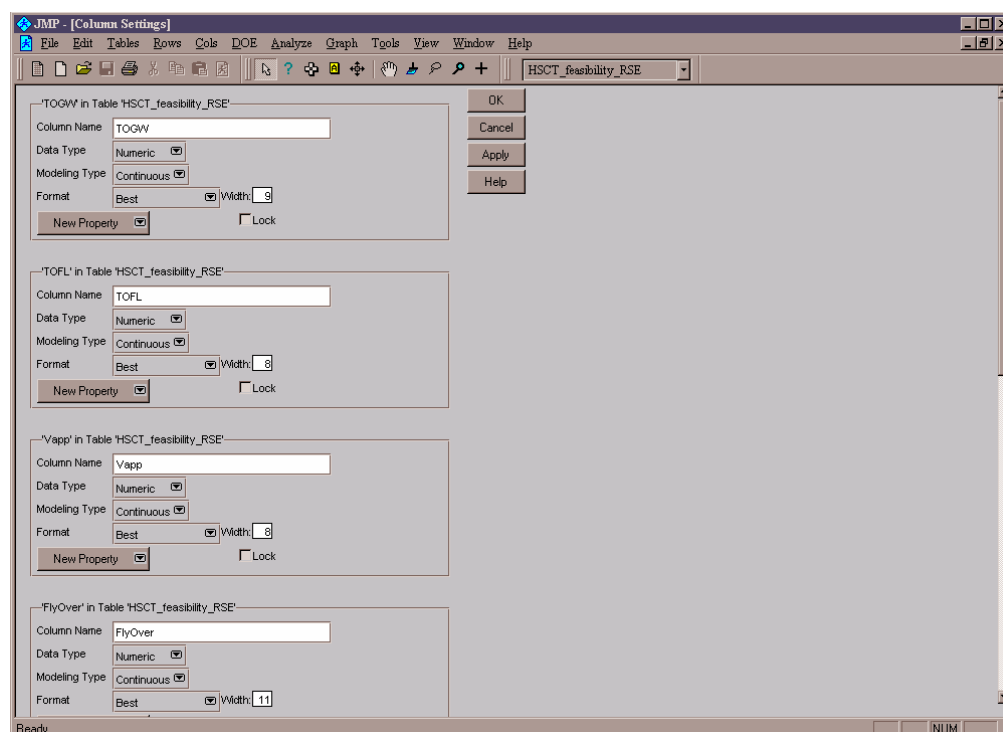
Scroll down in the window to see the “carpet” plot shown below. Here is where you can play with constraints that may be hurting you. You can change which variables are displayed in the contour by simply clicking in the boxes under “Horiz” and “Vert”. You can assign specific values to your responses by clicking in the boxes under “Contour” and adding values. You can put limits on the responses as either Hi (high) or Lo (low) limits. You can set the design variables to different values by moving the slide bars, etc. For presentation purposes, copy this in the same manner as you did before. An example of the contour plot is shown below. There are upper limits on 2 responses, and the design variables are all set at “0”. Note that the contour values were set to the limit values so that you can visualize which constraints are active. In this case, the TOGW and the TOFL are active constraints. Just play with this, it is VERY easy. Note, to expand the contour plot for easier viewing or presentation, put your cursor in the bottom right hand corner and then click and drag the corner of the box. You can also turn off the Surface Plots if you like under the drop menu for the Contour Profiler. You can zoom in and out on the contour plot by putting your mouse over one of the axes (either T/W or Wing_Area), hold the “Ctrl” key down and then right mouse click and select the “Size/Scale” option and then either X or Y axis. If you select the Y-axis, you get the window down below. You can modify any range you like.



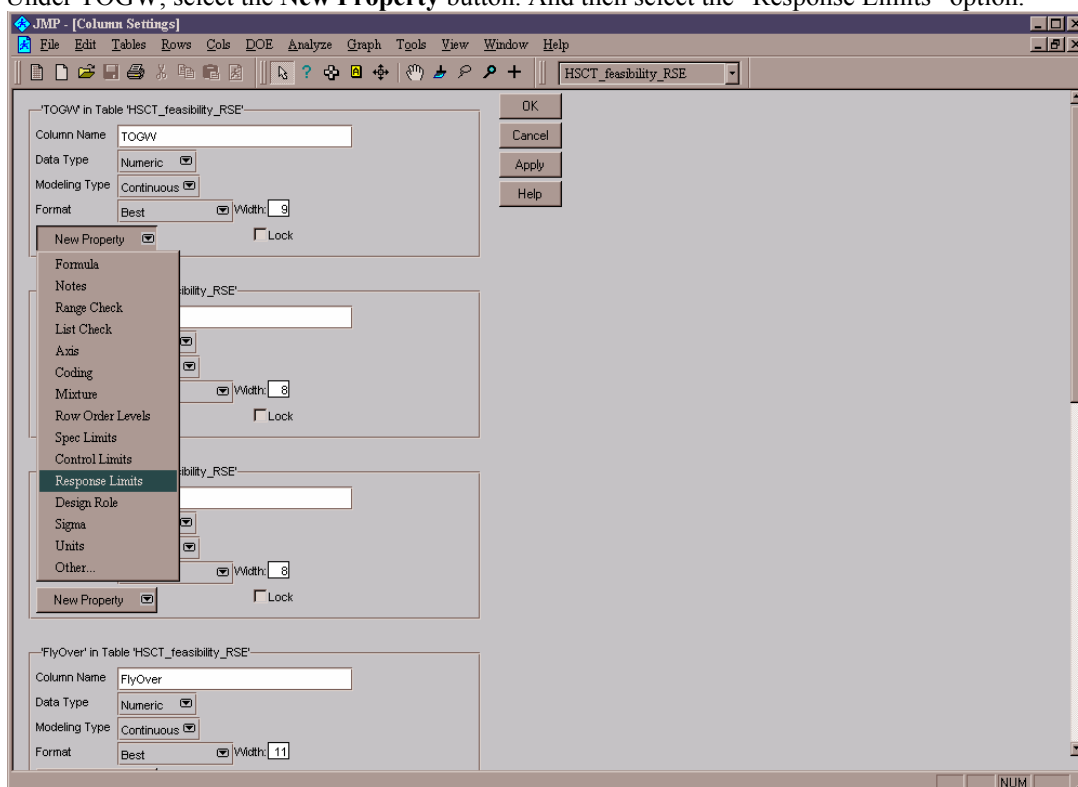
One item of interest to you might be the following: What are the settings of the variables that optimize my responses? JMP can optimize your variables for you through a feature called the “Desirability Function”. Consider our 8 responses, each of which we would like to minimize. We need to tell JMP this information. Go back to the DoE table and click on the first response column title cell, TOGW, and hold down the shift key and click the last response title cell (\$/RPM). Note that all of the column headings are highlighted. Now, right mouse click and you will get the following menu and select the **Column Info** option.



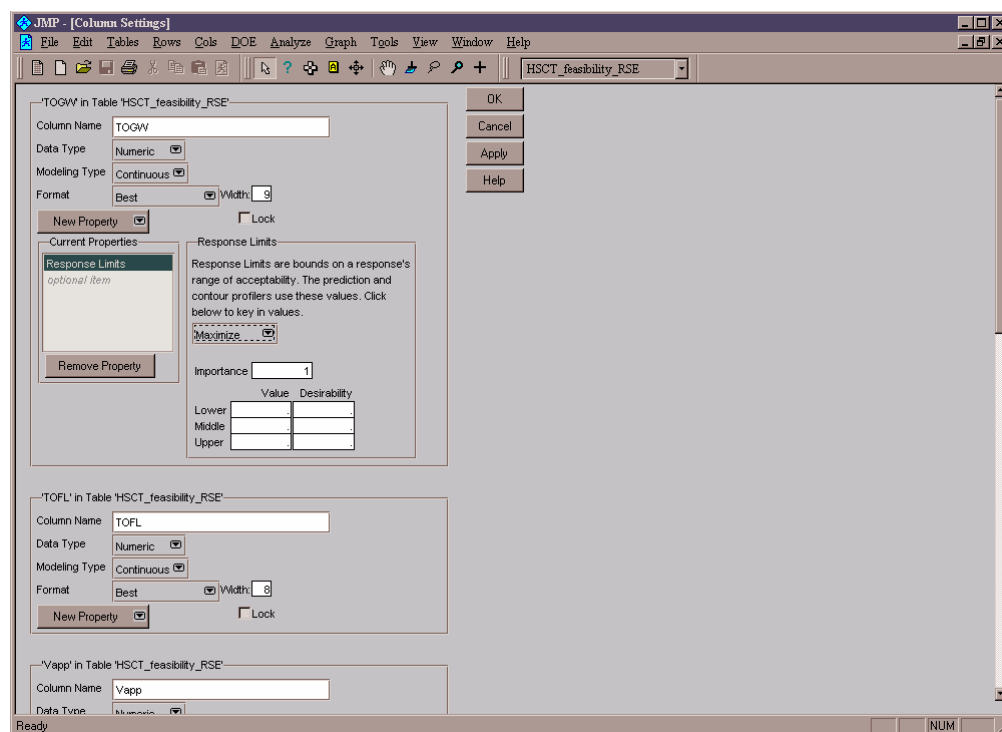
The window below will come up.



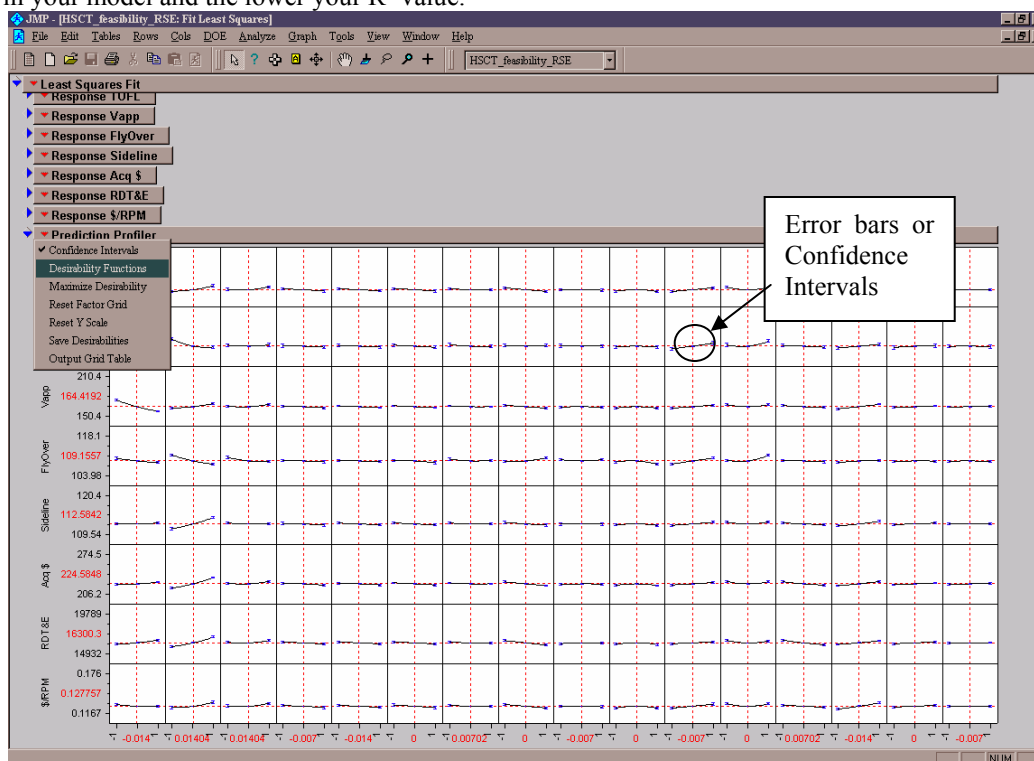
Under TOGW, select the **New Property** button. And then select the “Response Limits” option.



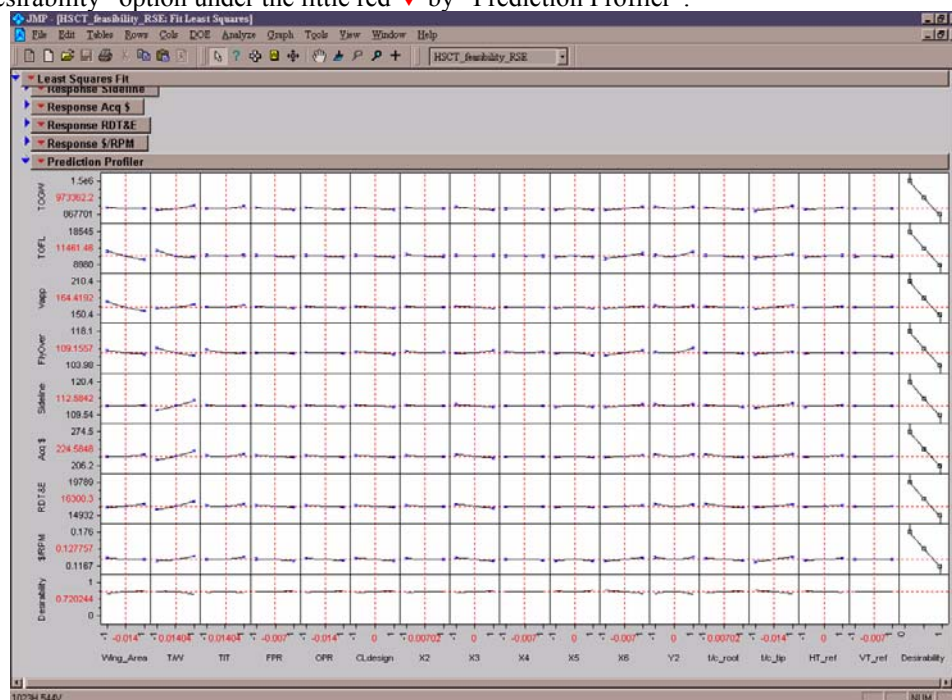
The following will come up. Click the **Maximize** button and change it to the “Minimize” option. This tells JMP that the response is to be minimized when we do the search for the most desirable settings. Repeat this for each response and then click the **Apply** button and then **OK** and go back and **Fit Model** again.



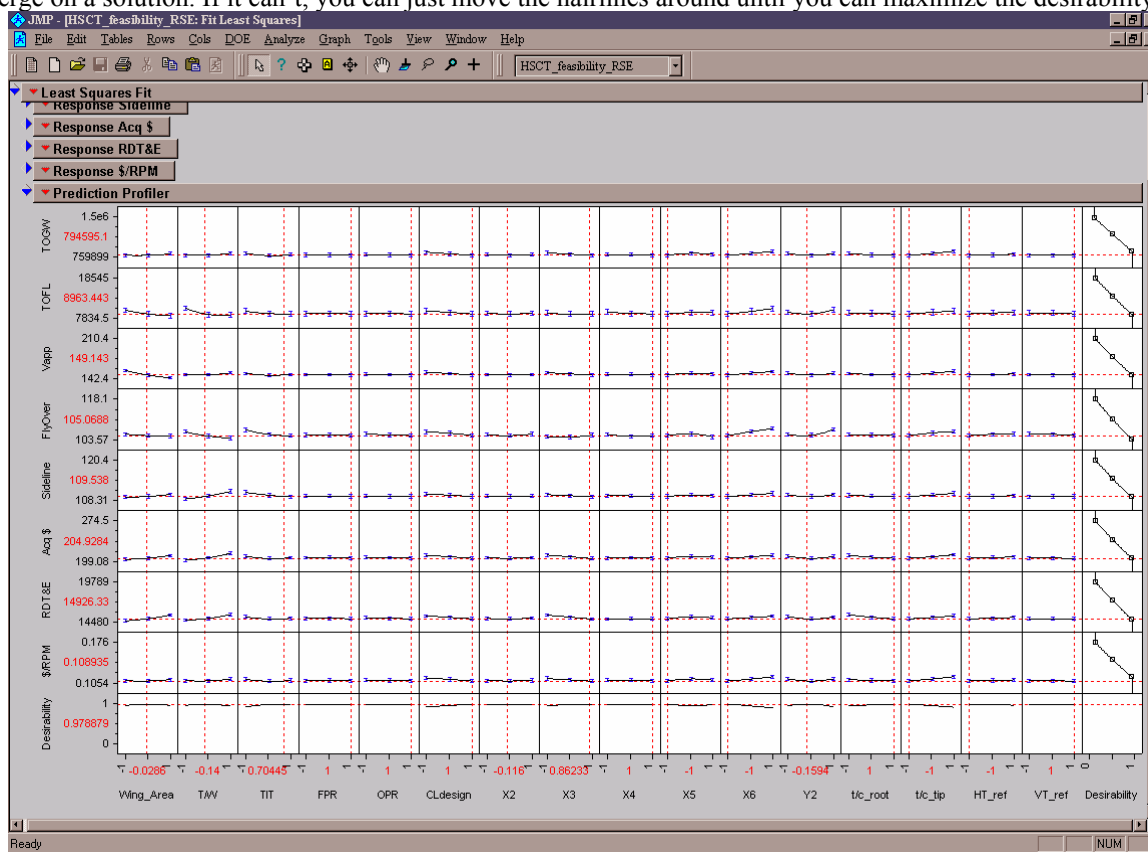
Go back to the “Least Squares Fit” window and go to the Prediction Profiler and click on the little red ▼ and select the “Desirability Functions” option. Notice that the “Confidence Intervals” are checked in the box below. The Confidence Intervals are the little error bars on the Prediction traces of the Profiler. The larger they are, the more error that exists in your model and the lower your R^2 value.



After you select the “Desirability Function” option, another column will appear in your Profiler and another row. On the right, this is the direction of the desired response; it is shown in minimization right now. If any of the responses were to be maximized, then the slope would be positive, rather than negative as shown. On the bottom, the influence of a variable on the desirability is shown. For example, increasing Wing_Area increases the desirability, reducing T/W increases desirability, and so on. JMP will automatically find the optimal settings by selection the “Maximize Desirability” option under the little red ▼ by “Prediction Profiler”.



JMP will then come back with the most desirable settings for the responses as shown below, if it in fact can converge on a solution. If it can't, you can just move the hairlines around until you can maximize the desirability.



Also, there is another way to change the desirabilities. Put your cursor in one of the desirability boxes on the right and hold down the “Alt” key and click. The window below will open up and you can change the options.

JMP: Response Goal

Minimize

Acq \$ Values

High:

Middle:

Low:

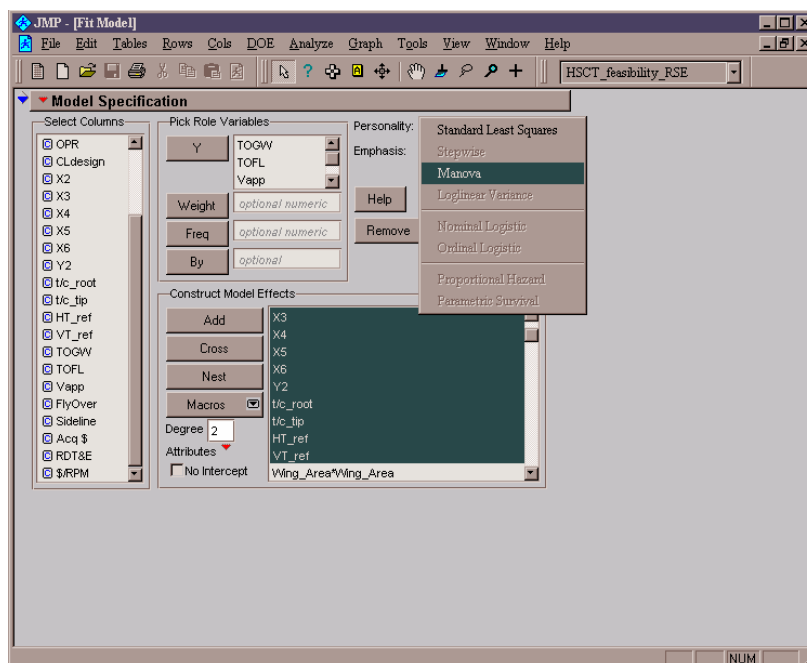
Importance:

OK Cancel

Let's summarize what we should have done up to this point.

- Look at the “Actual versus Predicted Plots” to check the goodness of fit
- Look at the “Residual Plots”
- Check the error distribution
- Exclude bad or high error cases
- Run random cases if you have strong interactions and large quadratic behaviors
- Check the R^2 value for EACH response
- If an acceptable value is obtained, we can proceed, if not, then we need to check what went wrong
- Modify ranges if needed and run another DoE
- Refit data
- Create Contour Plots and Prediction Profiler for presentation purposes

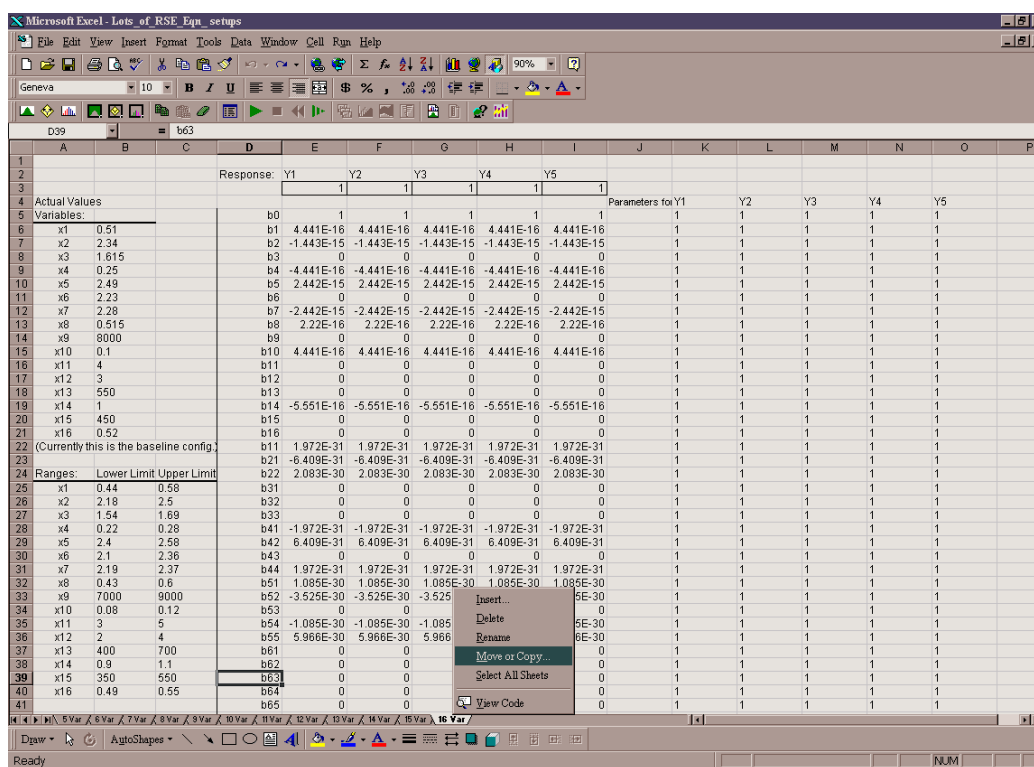
Let's press onwards with investigating the design space. We now want the coefficients for all of the responses. The easiest way to do this is to go back to the **Fit Model** window and select the **Manova** option under "Personality" menu then select **Run Model**.



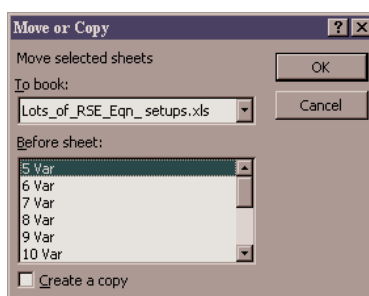
The window below will come up. Select the little cross icon from the menu bar and then click anywhere under the **Parameter Estimates** bar and all of the area will be highlighted. You will have an Excel file called *Lots_of_RSE_Eqn_setups*, which contains spreadsheets to calculate the RSEs for 5 to 29 variables.

	TOGW	TOFL	Vapp	FlyOver	Sideline	Acq \$	RDT&E	\$RPM
Intercept	973060.37	11467.0941	164.285989	109.189656	112.574972	224.519775	16298.379	0.12772696
Wing_Area	-8868.3172	-1227.4815	-8.4342734	-0.758713	0.08788811	1.70267925	249.08347	-0.0012045
TAV	40449.1072	-962.24719	3.33349819	-1.6515712	1.52189139	9.07872385	577.646999	0.00394093
TIT	17764.7064	15.1132707	1.44241292	-0.7031347	-0.1171661	1.57656106	110.913112	0.00189108
FPR	-15273.645	-183.74226	-1.2300152	-0.1875009	-0.2376579	-1.610495	-114.66713	-0.001478
OPR	-14859.247	-153.7218	-1.2024904	-0.1973735	-0.2259804	-1.4968479	-108.35697	-0.0014704
CLdesign	-18530.519	-268.81865	-1.5315176	-0.4522983	-0.2721921	-1.8369503	-129.12503	-0.001963
X2	-7708.4872	-209.83015	-0.6193227	-0.2271177	-0.1159689	-0.7495381	-52.536655	-0.0007876
X3	-26319.672	34.7999513	-2.1427579	0.61113476	-0.3681538	-3.294586	-273.70632	-0.0026404
X4	-1378.944	-30.238389	-0.1203253	-0.0123268	-0.0116364	0.26833449	44.2852335	-0.0002252
X5	-3382.7116	-21.412354	-0.2677072	-0.4098957	-0.0552945	-0.2429489	-12.400092	-0.0003646
X6	27971.7323	683.418543	2.28465381	1.05116421	0.42487331	2.11450092	114.468926	0.00301446
Y2	363.677908	459.360074	0.02668164	0.95080183	0.02916027	-0.2270625	-30.421	0.00008133
t/c_root	-16060.39	-214.56394	-1.318822	-0.2293574	-0.239273	-2.9149314	-279.83475	-0.0014889
t/c_tip	42608.6103	430.464249	3.47076537	0.42286833	0.61603441	3.58158622	221.128423	0.00453783
HT_ref	12793.3143	221.210451	1.04713449	0.10995547	0.18850374	1.54387097	112.968353	0.00128994
VT_ref	3713.20048	-32.872155	0.30287086	-0.0513493	0.04914077	0.35409006	25.8870692	0.00036915
Wing_Area*Wing_Area	12911.4579	266.002809	1.66114504	0.20260318	0.17692902	1.31173289	94.1900226	0.00143814

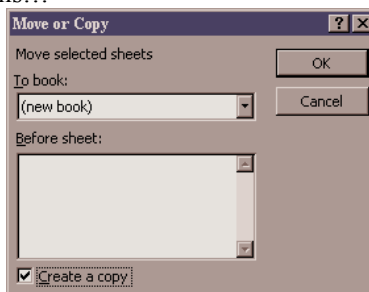
Open Excel and the *Lots_of_RSE_Eqn_setups* file. Go to the sheet that has the appropriate number of variables. Right mouse click on the sheet tab name as shown below and select “Move or Copy...”



The following window will come up. Under “To Book” select “(new book)” and click the “Create a copy” at the bottom.



Your window should look like this...



Go back to the *Lots_of_RSE_Eqn_setups* sheet and close it. Save your new file as “Feasibility_Investigate”. Click **Insert** and select “Worksheet”. Go back to JMP and copy the highlighted area by going to **Edit** and select **Copy**. Go back to Excel and go to **Edit** and then **Paste Special**, and then paste as **Unicode Text**. Your RSE coefficients will then be pasted into different cells on the new worksheet.

Microsoft Excel - Book2

File Edit View Insert Format Tools Data Window Cell Run Help

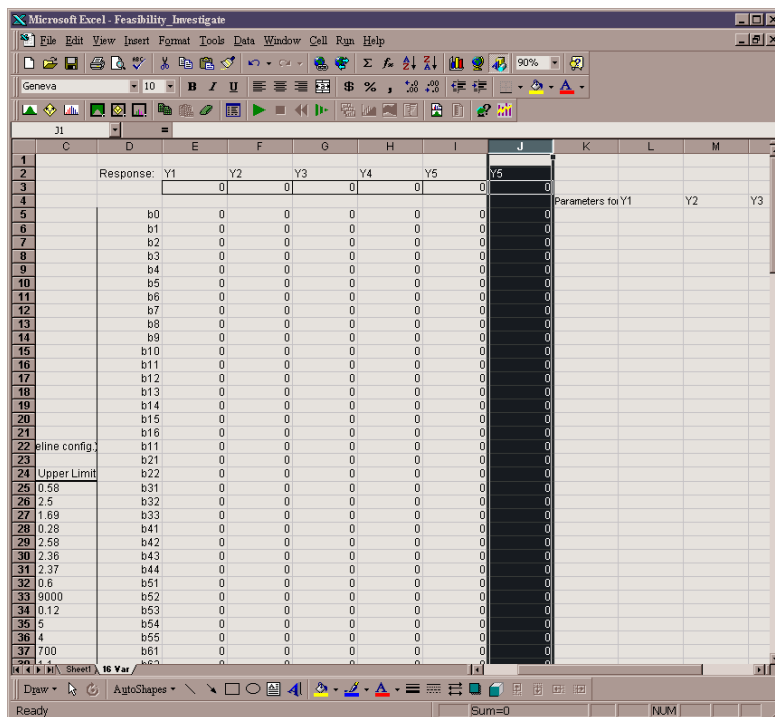
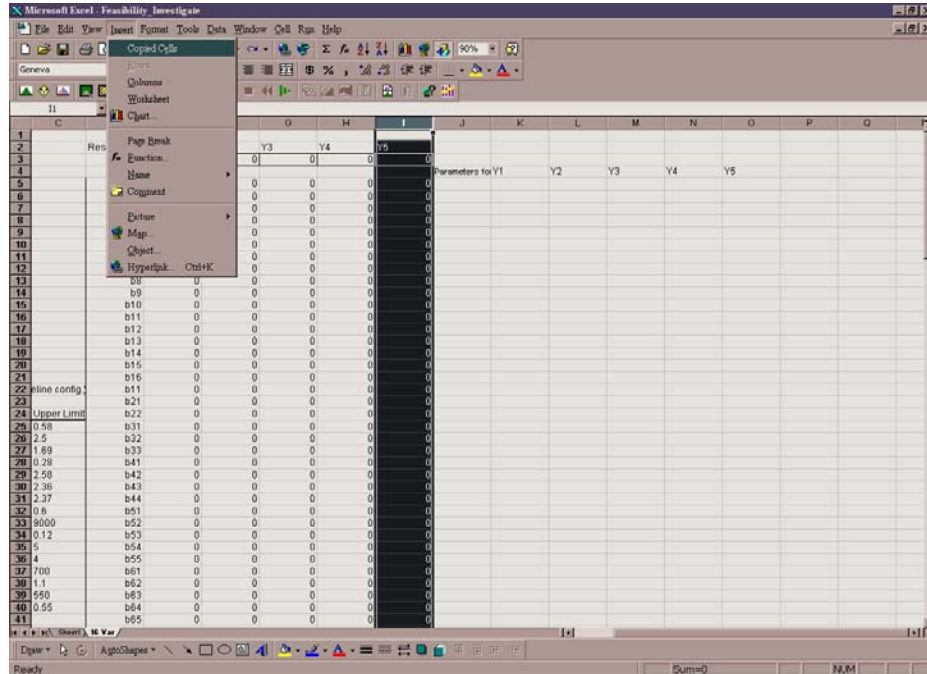
Geneva 10 B I U [Formatting icons]

A1

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
2		TOGW	TOFL	Vapp	FlyOver	Sideline	Acq \$	RDT&E	\$/RPM				
3	Intercept	973060.4	11467.09	164.286	109.1897	112.575	224.5198	16298.38	0.127727				
4	Wing_Area	-8868.32	-1227.48	-8.43427	-0.75871	0.087888	1.702679	249.0835	-0.0012				
5	TAW	40449.11	-962.247	3.333498	-1.65157	1.521891	9.078724	577.647	0.003941				
6	TIT	17764.71	15.11327	1.442413	-0.70313	-0.11789	1.576561	110.9131	0.001891				
7	FPR	-15273.6	-183.742	-1.23002	-0.1875	-0.23766	-1.6105	-114.667	-0.00148				
8	OPR	-14859.2	-153.722	-1.20249	-0.19737	-0.22598	-1.49685	-108.357	-0.00147				
9	CLdesign	-18530.5	-268.619	-1.53152	-0.4523	-0.27219	-1.83695	-129.125	-0.00196				
10	X2	-7708.49	-209.83	-0.61932	-0.22712	-0.11597	-0.74954	-52.5367	-0.00079				
11	X3	-26319.7	34.79995	-2.14276	0.611135	-0.36815	-3.29459	-273.706	-0.00264				
12	X4	-1378.94	-30.2384	-0.12033	-0.01233	-0.01164	0.268334	44.28523	-0.00023				
13	X5	-3382.71	-21.4124	-0.26771	-0.4099	-0.05529	-0.24295	-12.4001	-0.00036				
14	X6	27971.73	683.4185	2.284654	1.051164	0.424873	2.114501	114.4669	0.003014				
15	Y2	363.6779	459.3601	0.026682	0.950802	0.02916	-0.22706	-30.421	8.13E-05				
16	t/c_root	-16060.4	-214.564	-1.31882	-0.22936	-0.23927	-2.91493	-279.835	-0.00145				
17	t/c_tip	42608.61	430.4642	3.470765	0.422868	0.616034	3.581586	221.1284	0.004538				
18	HT_ref	12793.31	221.2105	1.047134	0.109955	0.188504	1.543871	112.9684	0.00129				
19	VT_ref	3713.2	-32.8722	0.302871	-0.05135	0.049141	0.35409	25.88707	0.000369				
20	Wing_Area	12911.46	266.0028	1.661145	0.202603	0.176929	1.311733	94.19902	0.001438				
21	TAW*Wing	-23695.6	-234.609	-2.06741	-0.29352	-0.34384	-2.32431	-164.039	-0.00247				
22	TAW*TAW	19255.76	755.0028	1.561145	0.409484	0.243554	2.029733	147.6865	0.002023				
23	TIT*Wing	-11290.3	-112.903	-1.12903	-0.112903	-0.112903	-1.12903	-112.903	-0.0012				
24	TIT*TAW	14066.83	140.6683	1.406683	0.140668	0.140668	1.406683	140.6683	0.001466				
25	TIT*TIT	26208.36	262.0836	2.620836	0.262084	0.262084	2.620836	262.0836	0.002443				
26	FPR*Wing	6486.077	94.66991	0.565844	0.099653	0.098312	0.623032	44.03201	0.000667				
27	FPR*TAW	-9279.64	-80.1777	-0.71897	-0.06328	-0.14971	-0.93468	-67.5657	-0.00096				
28	FPR*TIT	-10157.2	-113.514	-0.82444	-0.12805	-0.16075	-1.04604	-75.9983	-0.00093				
29	FPR*FPR	-5739.29	-77.4972	-0.48886	-0.1391	-0.07849	-0.63527	-40.2165	-0.00068				
30	OPR*Wing	5114.904	69.30381	0.458037	0.079105	0.078256	0.485302	34.49906	0.000546				
31	OPR*TAW	-8283.03	-80.2491	-0.66116	-0.07824	-0.1255	-0.84526	-60.4178	-0.00085				
32	OPR*TIT	-4054.24	-46.3194	-0.32913	-0.08277	-0.06536	-0.35797	-25.2034	-0.00043				
33	OPR*FPR	636.5962	14.71678	0.047094	0.013806	0.006647	0.019032	1.168411	8.51E-05				

Ready Sum=1075934.935 NUM

For this example, switch to the “16_var” sheet. Note, this template was set up for only 5 responses (Y1 through Y5). We have 8 responses so we need to add some more columns. To do so, click in column “I” header and go to **Edit** and select **Copy**. Then go to **Insert** and select **Copied Cells**. Excel adds an exact copy as you can see below. You need to copy the last column of responses (in this case Y5) and then insert that column. Make sure you check that the formulas were copied. Change the generic response names from Y1 and so on to your actual response names (i.e., TOGW). You should also put them in the row that contains the cell called “Parameters for:” to the right of all of the zeros.



Go back to the sheet where you pasted your coefficients from JMP and highlight cell A3 through the bottom of the coefficients, in this case that would be cell I155. Copy and then switch back to the “16 Var” sheet. Make the active cell the one DIRECTLY under the cell with “Parameters for:” in it. In this case, it would be J5 and then paste your info as shown below. You will see that column E through L fills out with numbers besides “0”. Now, you need to change the input variables (X1 through X16) to your actual variable names. In this case, X1 corresponded to Wing_Area, X2 was T/W, and so on. Do this for cells A6 through A21 and then A25 through A40 and A46-A61. You should put in your baseline values (in dimensional form) in cells B6 through B21. Then add the ranges that you used in your analysis code for the DoE. Put the minimum and maximum values in B25-B40 and C25-C40, respectively.

Summed value of RSE for current

IMPORTANT: Check to make sure cell references in the equations are correct

Add starting values

RSE coefficients from JMP

Add real ranges of variables here

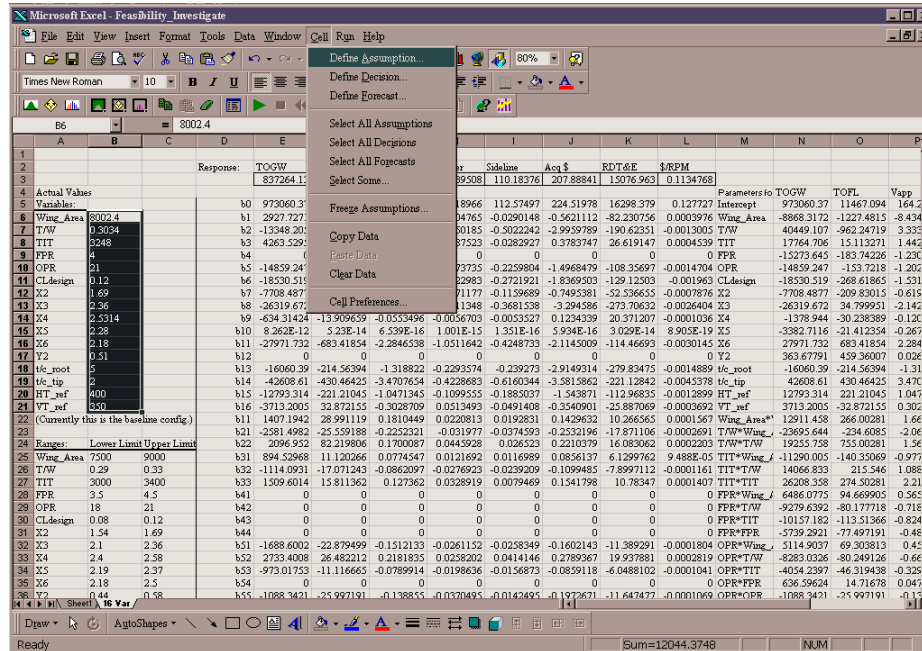
Change variable names

Once you have supplied all the info, now you are ready to run Crystal Ball.

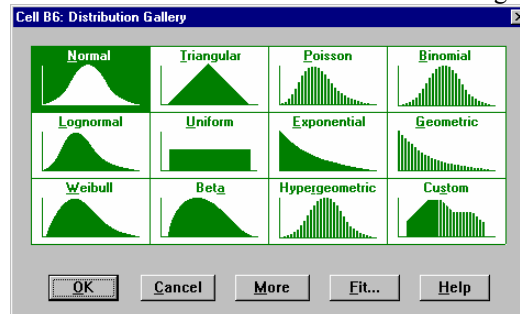
16 Var

Running Crystal Ball: A Monte Carlo Simulation

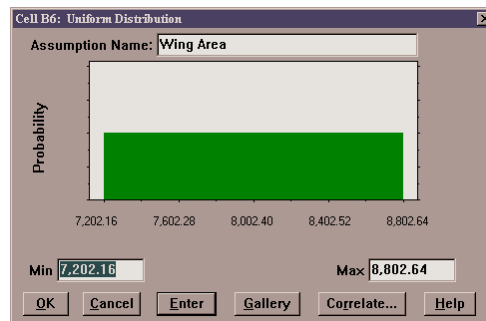
This is probably the easiest and quickest part of the whole method. You should still have your Excel spreadsheet from above open. Crystal Ball is already linked to Excel. If you do not have the drop menus in Excel entitled **Cell** and **Run**, contact Dr. Kirby. Else, let's continue. First you need to tell Crystal Ball which cells you want to vary. In this example, you will be doing your 7 design variables. So, highlight the 7 cells as shown below. Then, go to **Cell** and select **Define Assumption**.



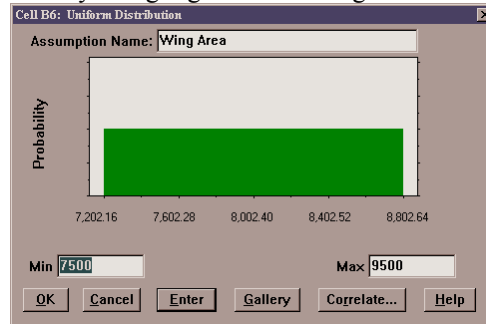
You will get the below window. For the feasibility investigation (i.e., design variable variation), you want all of your variables to be defined by a uniform distribution. Click in the uniform region and then hit **OK**.



Your first variable will come up as shown in the next window. In this example, it is AR (wing aspect ratio). You need to modify the distribution range by clicking in the **Min** and **Max** cells and changing the values to the ranges you used in your DoE.



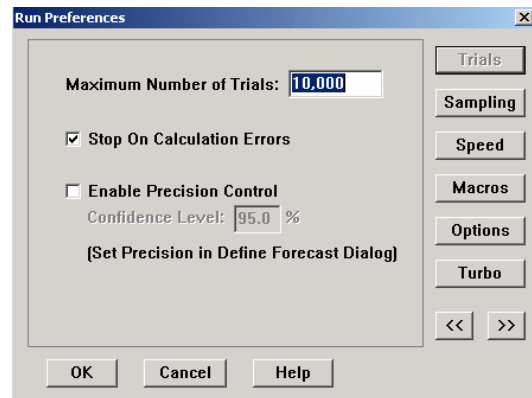
This is shown in the following window. Once you have done that, click **OK**. Repeat this for EVERY design variable. When you are done, the cells that you highlighted will change colors. This means they are ready to go.



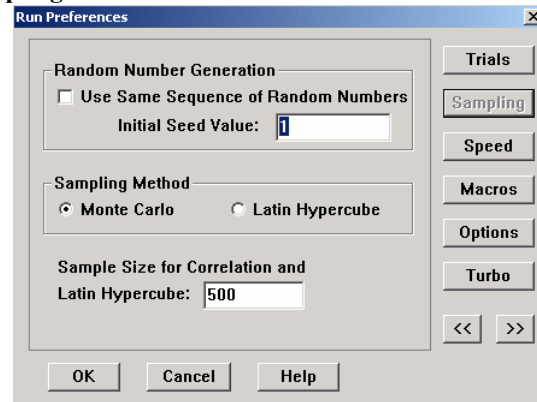
Now you need to define your forecasts (i.e., what you are interested in tracking). In this case, it is the 8 responses TOGW, TOFL, etc.. Highlight these 8 cells as shown below.

Click the **Cell** menu and select the **Define Forecast** option. You will get the following window. This is telling Crystal Ball that these cells are what you want to keep track of. Make sure that the **Forecast Window Size** is selected as **Small**, and the window is displayed **When Stopped**. Then click **OK**. Another window will pop up for the next metric. Do the same thing for all and when you are done, the forecast cells will change colors. Also, if the correct name of your response is not listed beside the “Forecast Name:” you may enter it at this time.

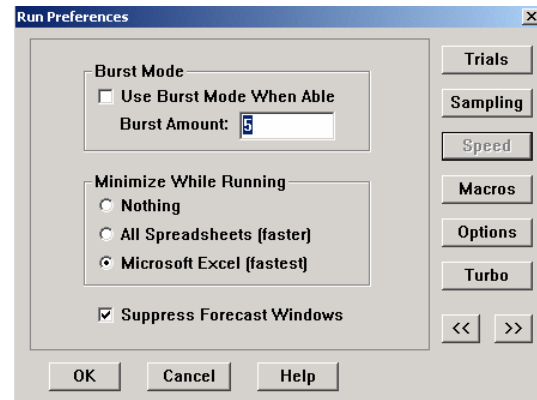
Go to the **Run** menu and select the **Run Preferences** option. Click on the **Trials** button and make sure it looks like the one below.



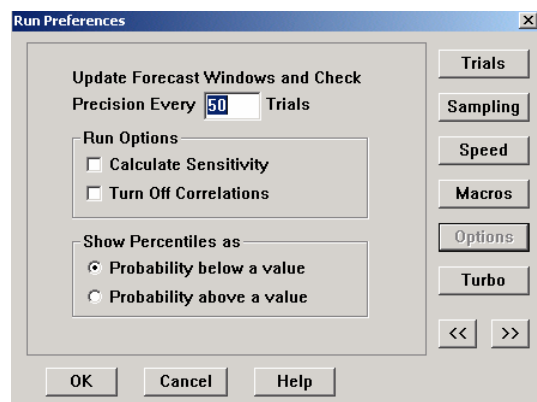
Then click on the **Sampling** button and make sure it looks like the one below.



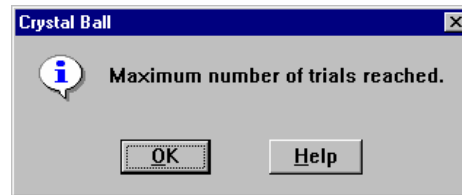
Then click on the **Speed** button and make it look like this one.



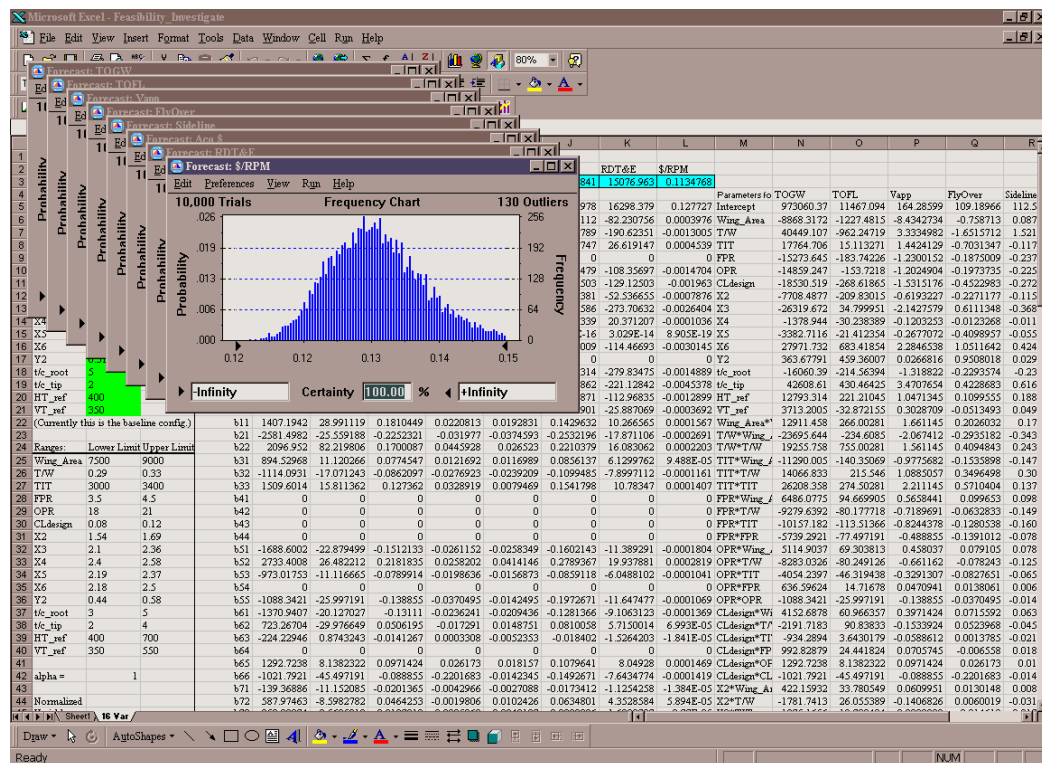
Then click on the **Options** button and make it look like this one.



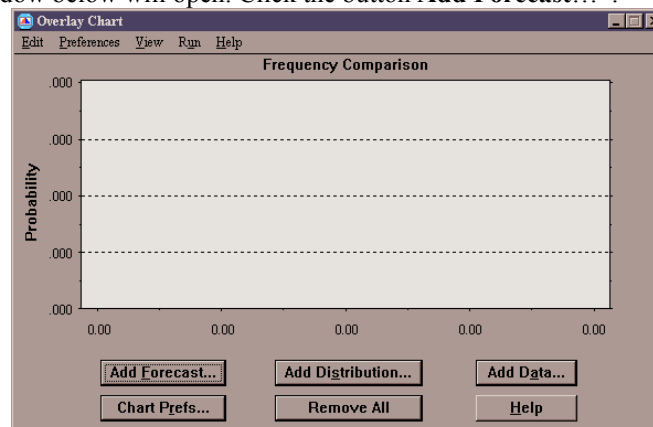
You are now ready to run Crystal Ball!!!!!! Go to the **Run** menu and select **Run**. Excel will automatically minimize itself to run faster. When Excel/Crystal Ball is done running the 10,000 simulations, it will pop back up with the following. Click **OK**.



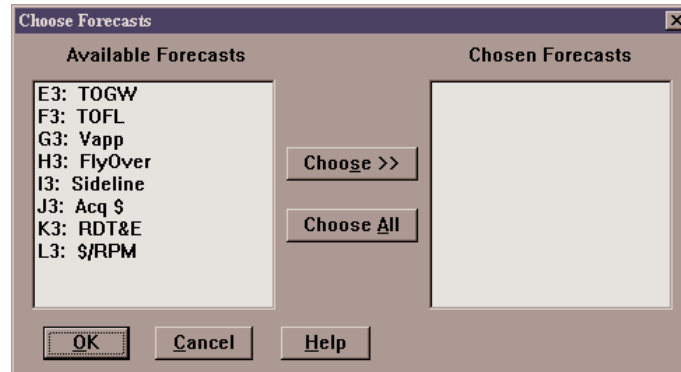
Once you click **OK**, the forecast windows will pop up as shown below. The windows are tiled and are the frequency distributions for your metrics as a function of the 7 design variables you had. You can sit and play with all of these windows. Look at the different options and the preferences. Crystal Ball is very straightforward.



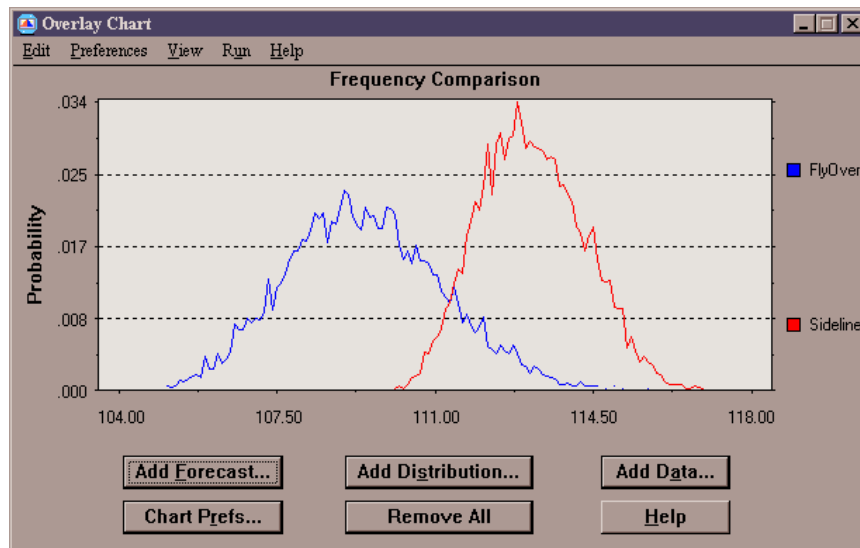
One of the more interesting features of Crystal Ball is the Overlay Option. Go to **Run** and select **Open Overlay Chart** and the window below will open. Click the button **Add Forecast...**



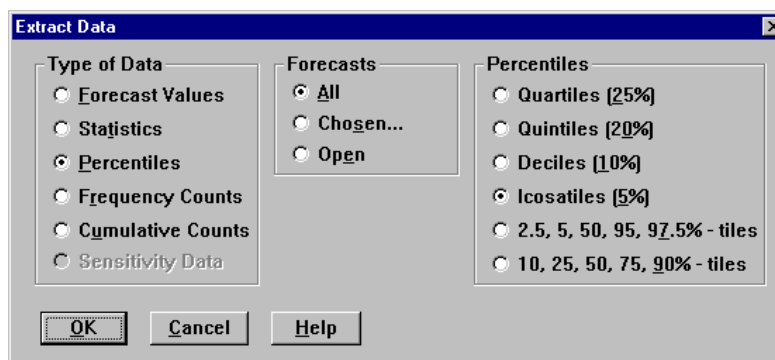
The window below will open. Now you can add different forecasts (responses) and look at them concurrently.



Let's look at the Flyover and the Sideline Noise. Click the Flyover and then click **Choose**, do the same for Sideline and select **OK**. The window below will come up and show you where the design space lies for the Sideline and Flyover noise level. Play with the "Preferences" and "Views" to get exactly the picture you want. You can also copy the Overlay chart by going to **Edit** and then **Copy**.



What you really want from the Monte Carlo Simulation are the values of the metrics for different probability levels. So, go under **Run** and select **Extract Data** and the window below will pop up. Make sure yours looks like the one below. Click **OK**. Or you can extract other info that interests you.

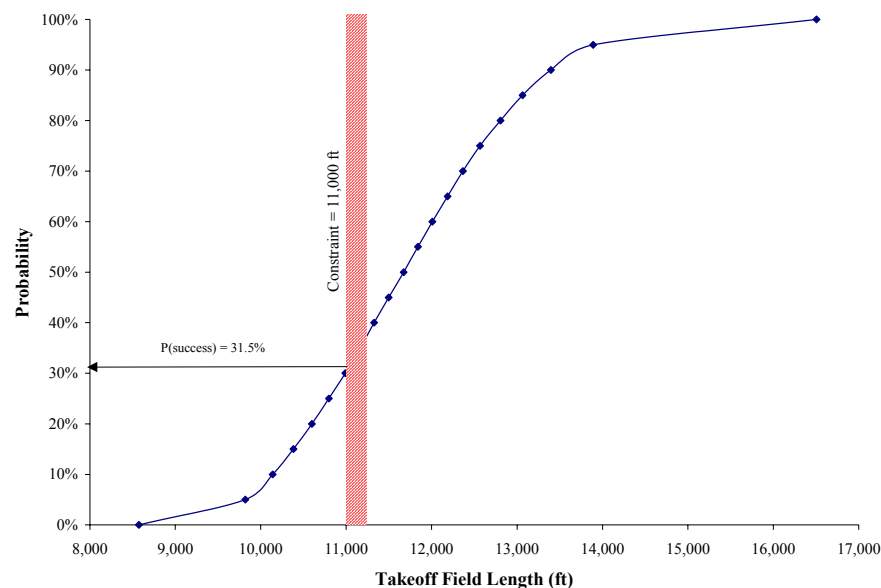


Excel/Crystal Ball will open another worksheet that looks like the one below. These are your response values for different probability percentages. In this form, you can make plots in Excel and overlay any other info you want.

Microsoft Excel - DATA1							
File Edit View Insert Format Tools Data Window Cell Run Help							
MS Sans Serif 10							
A1 Percentiles							
1	Percentiles	TOGW	TOFL	Vapp	FlyOver	Sideline	Acq \$
2	0%	862,870.39	8,574.31	149.13	104.10	110.03	209.12
3	5%	927,499.85	9,817.78	154.79	106.70	111.32	217.42
4	10%	942,006.04	10,138.62	156.23	107.26	111.67	219.65
5	15%	951,823.83	10,383.87	157.35	107.65	111.91	221.37
6	20%	960,664.03	10,597.88	158.31	107.95	112.11	222.73
7	25%	968,066.94	10,797.65	159.23	108.22	112.29	223.88
8	30%	975,497.30	10,989.62	160.00	108.46	112.45	224.97
9	35%	982,615.87	11,161.76	160.80	108.69	112.62	225.98
10	40%	988,727.26	11,327.09	161.69	108.92	112.77	227.00
11	45%	994,880.81	11,497.31	162.57	109.12	112.91	227.99
12	50%	1,001,195.66	11,673.59	163.45	109.36	113.07	229.01
13	55%	1,007,456.01	11,841.19	164.47	109.58	113.23	230.00
14	60%	1,013,973.39	12,008.20	165.60	109.83	113.39	231.04
15	65%	1,021,006.37	12,187.26	166.74	110.05	113.57	232.09
16	70%	1,028,538.32	12,366.53	168.00	110.30	113.74	233.20
17	75%	1,037,055.72	12,566.00	169.41	110.59	113.93	234.43
18	80%	1,047,021.32	12,805.91	170.87	110.90	114.15	235.93
19	85%	1,058,758.78	13,064.18	172.60	111.25	114.41	237.47
20	90%	1,074,710.82	13,395.46	174.91	111.72	114.70	239.55
21	95%	1,099,342.99	13,890.93	177.98	112.45	115.10	242.22
22	100%	1,244,872.10	16,505.10	193.43	115.99	117.09	257.81
23							
24							
25							
26							
27							
28							
29							

Step 5: Determine System Feasibility and Viability

Once you have the results of the Monte Carlo Simulation, you want to compare your results to your targets. An example plot is shown below. The TOFL is the metric. The constraint is 11,000 ft as shown. The probability, or amount of the design space investigated, that will satisfy the constraint value is 31.5%. You need to make a plot like this for *every* metric that you are considering. Recall the CDF that you have represents all the possible geometric combinations as bound by the design variable ranges that you defined. Finally, tabulate your results and find out which constraint is hurting your feasibility and viability.



Step 6: Specify Technology Alternatives

The objective of this step is three fold. One, identify potential technologies that may improve technical feasibility and economic viability of your vehicle. Second, establish physical compatibility rules for the different technologies identified. Third, determine the expected impact, both improvements and degradations, to the system of interest. The impact of a technology can be qualitatively assessed with technology metric “k” factors. These “k” factors modify disciplinary technical metrics, such as specific fuel consumption, cruise drag, and/or component weights that result from some analysis or sizing tool. The modification is essentially a change in the technical metric, either enhancement or degradation. In effect, the “k” factors simulate the discontinuity in benefits and/or penalties associated with the addition of a new technology. Once you have identified the impacts, you need to match the “k” factors to the appropriate FLOPS/ALCCA variables and namelists.

For step 6, the potential technologies are identified from the Morphological Matrix you created in Step 2. For the HSCT, eleven technologies and technology programs are considered. The technologies along with the primary purposes were identified through a literature search of potential sub-component. It is important to identify technology that will assist “show-stoppers”. In the HSCT example, the “show-stoppers” are noise and economic factors. Two technologies that assisted the sound metrics are being considered. The other technologies selected are an attempt to improve the economic metrics through secondary effects. The “Show-stoppers” have a large influence on what technologies you select to consider adding to your design.

Technology Readiness Level

Many of the identified technologies are in the development stage. It is important to identify how advanced they are and one way to do this is to use the technology readiness level. The technology readiness level (TRL) represents the amount of progress that has been made on a technology. On a scale of one to nine, the higher TRL a technology has the more tests and integration it has gone through. A higher TRL is also associated with less uncertainty concerning the final impact, so when evaluating the impact of the technologies on the vehicle, less uncertainty will need to be incorporated. The TRL of a technology affects the certainty of the outcome, and when evaluating technologies with lower TRLs on the vehicle there is a lower probability of having a feasible and viable design.

Table 6: Technology Readiness Levels

Description	Level	Qualifier or Development Hurdle
Basic Research	1	Basic scientific/engineering principles observed and reported
Feasibility Research	2	Technology concept, application, and potential benefits formulated (candidate system selected)
Feasibility Research	3	Analytic and/or experimental proof-of-concept completed (proof of critical function or characteristic)
Technology Development	4	System concept observed in laboratory environment (breadboard test)
Technology Development	5	System concept tested and potential benefits substantiated in a controlled relevant environment
System Development	6	Prototype of system concept is demonstrated in a relevant environment
System Development	7	System prototype is tested and potential benefits substantiated more broadly in a relevant environment
Operational Verification	8	Actual system constructed and demonstrated, and benefits substantiated in a relevant environment
Operational Verification	9	Operational use of actual system tested, and benefits proven

Table 7: HSCT Technologies

(Identifier) Technology	TRL	Primary Purpose
(T1) Composite Wing	3	Wing weight reduction
(T2) Composite Fuselage	3	Fuselage weight reduction
(T3) Circulation Control	4	Increased low speed performance
(T4) Hybrid Laminar Flow Control	3	Cruise drag reduction
(T5) Environmental Engines	3	Reduce noise, fuel burn, and emissions
(T6) Advanced Flight Deck Systems	4	Synthetic vision removes fuselage nose droop weight penalty
(T7) Advanced Propulsion Materials	3	High temp. materials, reduced engine weight, lower fuel burn
(T8) Integrally Stiffened Aluminum Wing Structure	4	Wing weight and part complexity reduction
(T9) Smart Wing Structures	3	Reduced flutter and wing weight
(T10) Active Flow Control	3	Cruise drag reduction
(T11) Active Acoustic Control	3	Noise suppression

Compatibility Matrix

It is not possible, however, to add all of these technologies onto a single design because some are incompatible. Technologies are incompatible when they compete for the same space on the aircraft or when one technology causes extreme degradation in the function or integrity of another. For example, technologies 1 and 8, the composite wing and the integrally stiffened aluminum wing structure, are incompatible because they are competing wing material technologies. All of the incompatibilities in the technology compatibility matrix (TCM) below result from this competition for the same design space or from extreme degradation effects.

Now you need to provide a compatibility matrix for your technologies. This matrix formalizes which technologies are physically compatible and as a by-product, reduces the number of alternatives to evaluate. This is important if the number of technologies considered for application is large and the combinatorial problem is out of hand. A sample compatibility matrix is shown below for 11 technologies. A “1” represent compatible technologies while a “0” implies an incompatible combination. The TCM is a symmetric matrix so only half of it is filled in. A TCM is easily created by researching the possible technologies and seeing which ones compete for design space or severely degrade the intended function or integrity of the technologies.

Compatibility Matrix (1: compatible, 0: incompatible)		Aircraft Morphing										
		Composite Wing	Composite Fuselage	Circulation Control	HLFC	Environmental Engines	Flight Deck Systems	Propulsion Materials	Integrally, Stiffened Aluminum Airframe Structures (wing)	Smart Wing Structures (Active Aeroelastic Control)	Active Flow Control	Acoustic Control
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Aircraft Morphing	Composite Wing	1	1	1	0	1	1	1	0	0	0	0
	Composite Fuselage		1	1	1	1	1	1	1	1	1	1
	Circulation Control			1	1	1	1	1	1	1	1	1
	HLFC				1	1	1	1	0	0	0	1
	Environmental Engines					1	1	1	1	1	1	0
	Flight Deck Systems						1	1	1	0	1	1
	Propulsion Materials							1	0	1	1	1
	Integrally, Stiffened Aluminum Airframe Structures (wing)								1	0	1	1
	Smart Wing Structures (Active Aeroelastic Control)									1	1	1
	Active Flow Control										1	1
	Acoustic Control											1

Technology Impact Matrix

Once the compatibility matrix is determined, the influence of infusing these technologies must be determined. This is difficult to evaluate directly, but it can be quantitatively evaluated through “k” factors. These “k” factors describe the potential system and sub-system level impacts of each technology. The impact must include benefits and degradations to the entire system. These “k” factors allow for the impact of the technologies to be evaluated using an M&S environment.

The impact of each technology is determined through physics based modeling, literary research and questioning experts. This impact is based on the upper limit of the technology at full maturity and widespread application. The impact for each “k” factor defines a “k” vector for the technology. A technology may not have an influence in all of the “k” factors. The “k” vectors for each technology are combined into the Technology Impact Matrix (TIM).

An example TIM is shown below for the HSCT example. Also note to the right is the max and min values that a given “k” factor could ever achieve if all technologies were “on”. The minimum and maximum values define the ranges you will use for the generation of your metric RSEs as a function of “k” factors, in lieu of design variables.

Technology Impact Matrix (TIM)												
Aircraft Morphing												

Now you need to map these “k” factors to *actual* inputs to FLOPS/ALCCA (or your analysis code) and useable values. An example is shown below for the TIM provided above. Each of the “k” factors is mapped to a FLOPS/ALCCA input and namelist. The baseline values are established so as to determine how to deviate the input variable in accordance with a DoE. For example, the baseline engine weight is 9,238 lb. The minimum value is determined by the following: $9,238 + 9,238 * (-0.1) = 8314.2$. The maximum is then $9,238 + 9,238 * (0.46) = 13487.48$. Hence, the non-dimensional baseline value is -0.6428 . You need to understand the dimensional minimum and maximum of your “k” factors if the non-dimensional impact is NOT symmetric about your baseline dimensional values. This is important for when you map the technologies to your RSEs.

		Variable	Namelist	Baseline value	Non-Dimensional Baseline Value	Dimensional impact		Non-dimensional impact	
						Min	Max	Min (%)	Max (%)
Technical Metric K_Factors	Wing Weight	FRWI	WTIN	1	0.66666667	0.65	1.07	-35	7
	Fuselage Weight	FRFU	WTIN	1	1	0.60	1.00	-40	0
	Engine Weight	WENG	WTIN	9238	-0.642857143	8314.20	13487.48	-10	46
	Electrical Weight	WELEC	WTIN	1	-1	1.00	1.22	0	22
	Avionics Weight	WAVONC	WTIN	1	-1	1.00	1.21	0	21
	Surface Controls Weight	FRSC	WTIN	1	-0.333333333	0.95	1.10	-5	10
	Hydraulics Weight	WHYD	WTIN	1	0	0.95	1.05	-5	5
	Noise Suppression	FSUPP	n/a	1	1	0.79	1.00	-21	0
	Subsonic Drag	FCDSUB	MISSIN	1	1	0.81	1.00	-19	0
	Supersonic Drag	FCDSUP	MISSIN	1	1	0.76	1.00	-24	0
	Subsonic Fuel Flow	FFFSUB	ENGDIN	1	0.333333333	0.94	1.03	-6	3
	Supersonic Fuel Flow	FFFSUP	ENGDIN	1	0.714285714	0.94	1.01	-6	1
	Maximum Lift Coefficient	CLMAX	AERIN	1	-1	1.00	1.15	0	15
	O&S	AKOANDS	IWGT	0	-0.789473684	-0.02	0.17	-2	17
	RDT&E	AKRDTE	IWGT	0	-1	0.00	0.39	0	39
	Production costs	AKPRICE	IWGT	0	-0.428571429	-0.12	0.30	-12	30

Step 7: Assess Technology Alternatives

The technologies identified in Step 6 are now applied to the vehicle concept and evaluated. The evaluation provides data and information to the decision-maker whereby selection of the proper mix of technologies is performed. Yet, the search for the mix that will satisfy the customer requirements is dominated by the “curse of dimensionality”. Depending on the number of technologies (n) considered, the combinatorial problem can be enormous. If all combinations are physically compatible and assuming only an “on” or “off” condition, then 2^n combinations would exist. In addition, the technology “k” factor vector that influences a vehicle is probabilistic and a cumulative distribution function (CDF) must be generated for each combination, further complicating the evaluation. If the computational expense of the analysis is acceptable, a full-factorial investigation could ensue. For the purpose of this tutorial, the evaluation will be completed deterministically, then probabilistically.

For this tutorial, the computational expense is manageable due to the means by which the technology “k” vectors are modeled. Consider the TIM given before and a metamodel representation of a system response. If one were to bind each “k” factor element of the technical vector, a metamodel in the form of a second-order Response Surface Equation (RSE) could be generated for each of the system level response. Hence, the system response could be defined as a function of the “k” factors for a fixed geometry using the equation below, through a Design of Experiments.

$$R = b_o + \sum_{i=1}^k b_i k_i + \sum_{i=1}^k b_{ii} k_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^k b_{ij} k_i k_j \quad (1)$$

To understand the use of the RSE, consider a single technology (T1). If an RSE was generated for three “k” factors: k_1 , k_2 , and k_3 , it would take on the form:

$$R_{|T1} = b_o + \left(\sum_{i=1}^3 b_i k_i + \sum_{i=1}^3 b_{ii} k_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 b_{ij} k_i k_j \right)_{|T1}$$

$$R_{|T1} = b_o + (b_1 k_1 + b_2 k_2 + b_3 k_3 + b_{11} k_1^2 + b_{22} k_2^2 + b_{33} k_3^2 + b_{12} k_1 k_2 + b_{13} k_1 k_3 + b_{23} k_2 k_3)_{|T1}$$

The impact of T1 is to reduce k_1 by 10%, increase k_2 3%, and to have no impact on k_3 . Using these values in the RSE yields:

$$R_{|T1} = b_o + b_1(-10\%) + b_3(3\%) + b_{11}(-10\%)^2 + b_{33}(3\%)^2 + b_{13}(-10\%)(3\%)$$

This procedure is repeated for all of the technologies and metrics that are considered. The coefficients (b_o , b_1 , b_{11} , etc...) are determined by the least squares analysis of the DoE

To find the RSE, go through the same process that you did in the design space exploration.

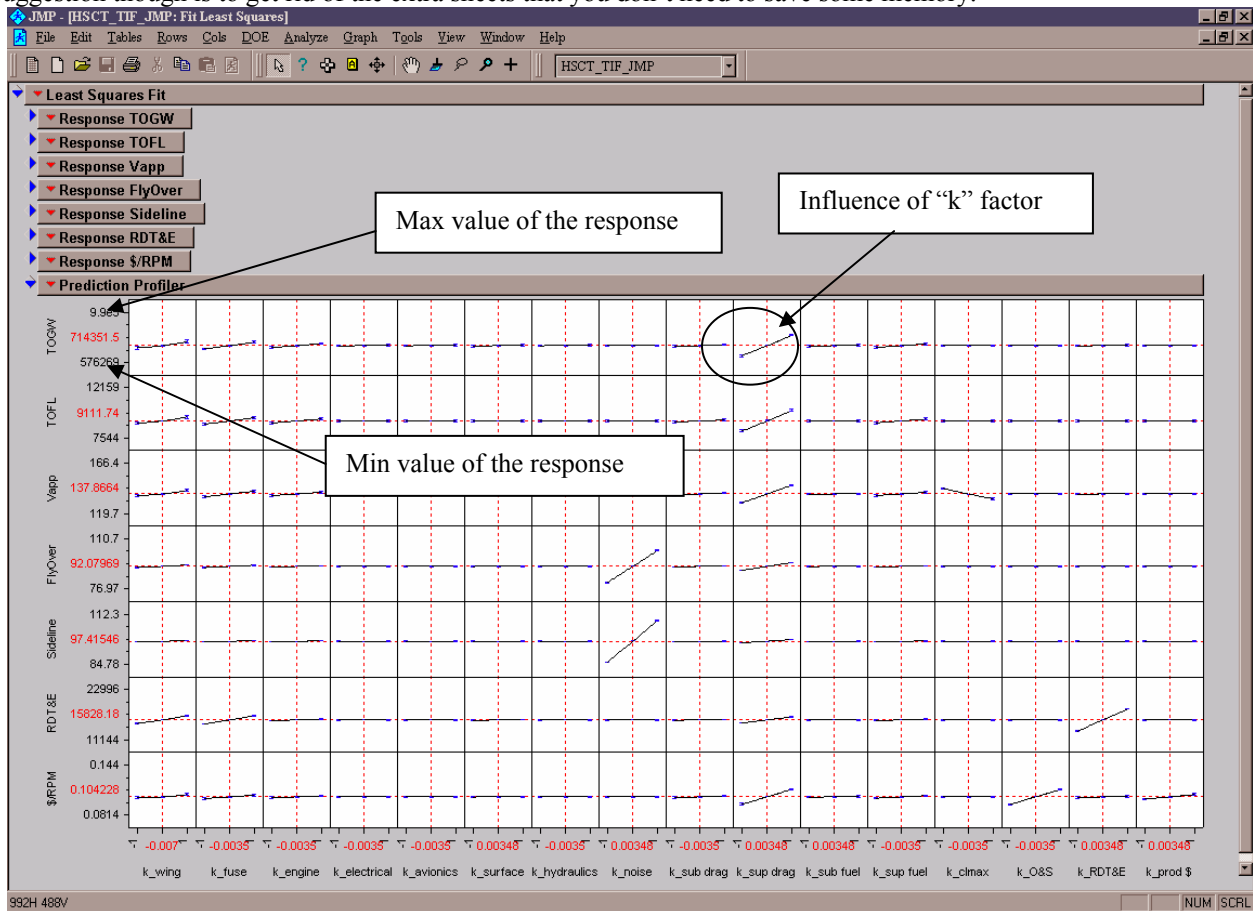
- generate a DoE or use one that was created if you have more than 8 variables,
- copy the table to Excel,
- save as “doe.table”,
- take the “doe.table” to UNIX and run the appropriate shell scripts,
- extract data, and
- bring data back to JMP and create your RSEs just as you did with the design space

When you go to the model fit of your RSEs, you will get the Technology Impact Forecasting (TIF) environment, as shown below. This environment allows you to see which discipline will help you most with respect to improving certain metrics. For example, you can see that “k_noise” significantly reduces the SLN (sideline noise) and FON (flyover noise). In addition, “k_supersonic_drag” significantly reduces almost every metric. This is a good environment to see *if* you can even get anywhere near your response targets. For example, look at the minimum and maximum values of the response (on the left). These values represent some arbitrary combination of “k” factor settings. If the minimum or maximum *does not contain* the desired metric constraint value, then the technologies that you are considering will not help you. NO MATTER WHAT COMBINATION. You should identify technologies that are more aggressive.

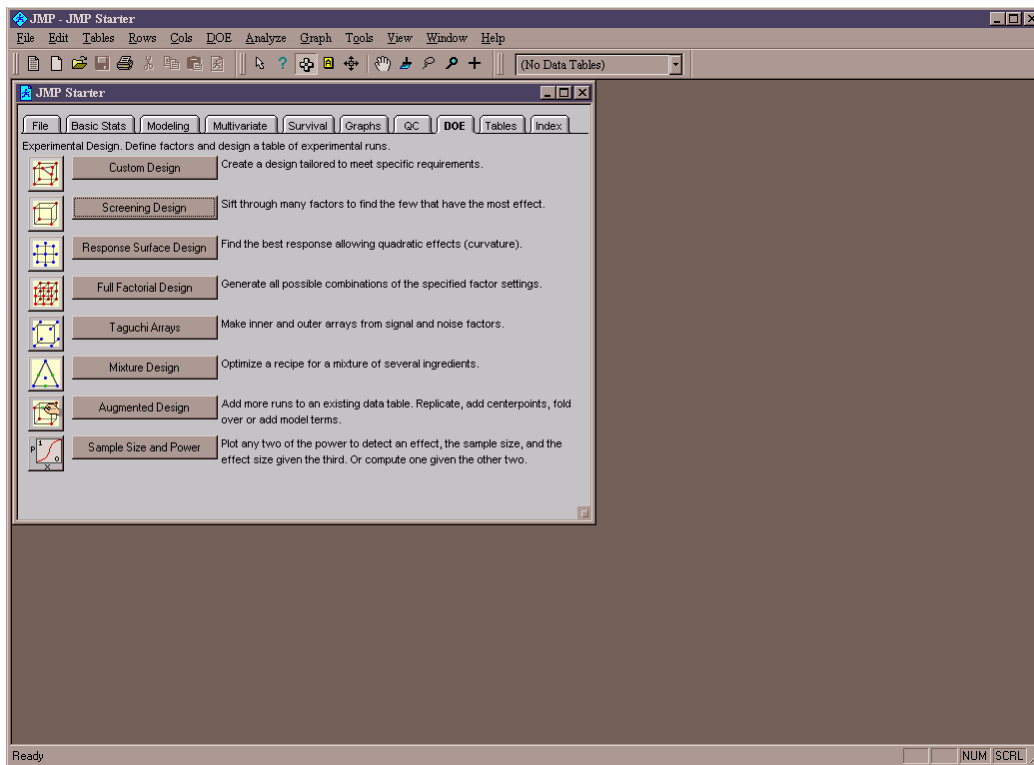
Another aspect of this Profiler is that you could reverse engineer the problem and determine what values of the “k” factors create a feasible configuration. This is the heart of the TIF method. Thus, once the “k” factor values are established, the decision-maker must identify specific technologies providing the predicted values. The reverse

approach was taken herein, such that specific technologies were identified for infusion, and the TIF environment was a fallout of this approach.

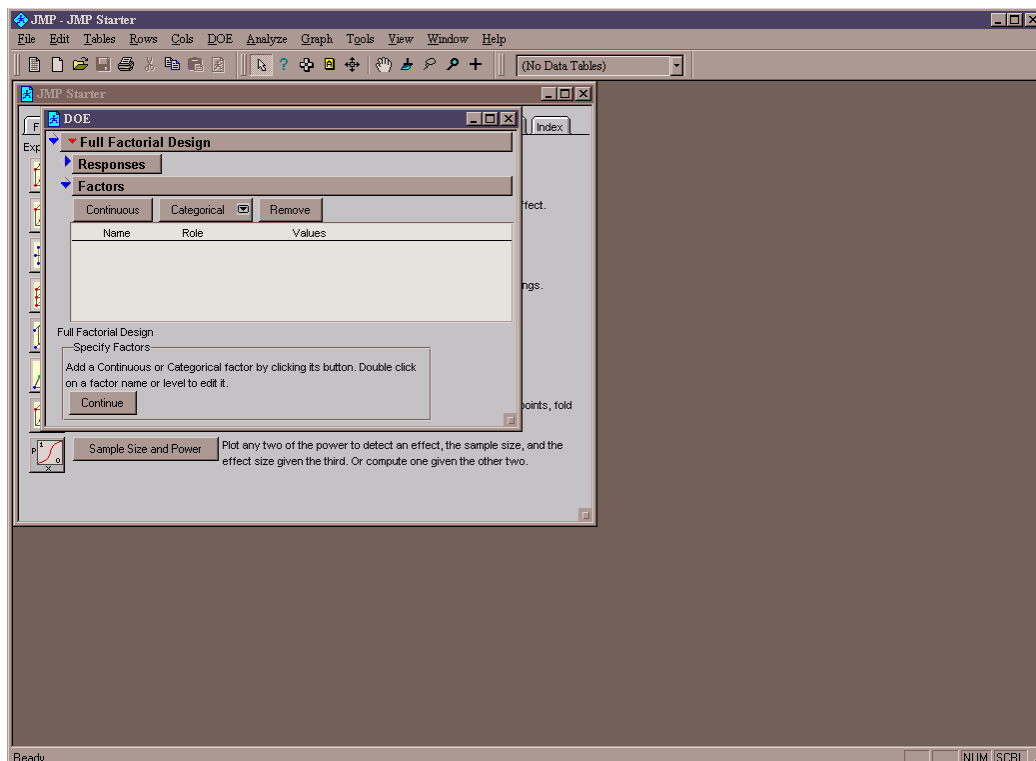
Go through the same process of getting your RSE coefficients by analyzing with a **Manova** as you did previously. Again, take the RSE's to the *Lots_of_RSE_Eqn_setups* Excel file. Save the file as what ever you like. One suggestion though is to get rid of the extra sheets that you don't need to save some memory.



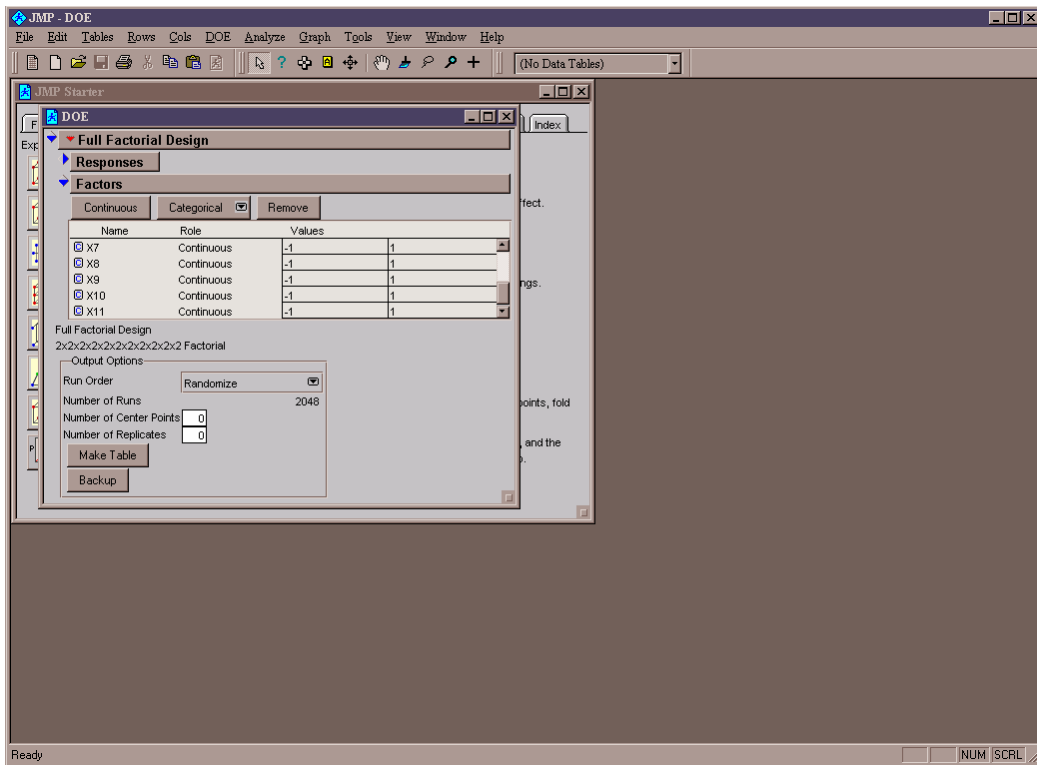
Now, you also need to create another JMP file that has a full-factorial DoE for your technologies. To do this, go back to the **JMP Starter** menu and select the **Full Factorial Design** button.



And the following screen will pop up. To add the number of technologies that you have, just hit the **Continuous** button for as many technologies as you have. In our case, we have 11. So we hit the **Continuous** button 11 times and then select **Continue**.



When you hit **Continue** the window will expand and look like the window below. Again change the “Run Order” to “Keep the Same”, but DO NOT add a center point and then hit **Make Table**.



When you are done you will get the DoE below. As you can see, there are 2,048 rows which corresponds to 2^n , where $n=11$ (the number of technologies). The factor is 2 since you are only going to consider an “off” or “on” condition, i.e., “-1” or “+1”. Now you can change the variables from X1 to T1 and X2 to T2 and so on. Add the appropriate number of response columns and save the file.

Pattern	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	Y
1 -----	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	*
2 -----+	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	*
3 -----+	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	*
4 -----++	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	*
5 -----++	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	*
6 -----++	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	1	*
7 -----++	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1	*
8 -----++	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	*
9 -----++	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	*
10 -----++	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	1	*
11 -----++	-1	-1	-1	-1	-1	-1	-1	1	-1	1	-1	*
12 -----++	-1	-1	-1	-1	-1	-1	-1	1	-1	1	1	*
13 -----++	-1	-1	-1	-1	-1	-1	-1	1	1	-1	-1	*
14 -----++	-1	-1	-1	-1	-1	-1	-1	1	1	-1	1	*
15 -----++	-1	-1	-1	-1	-1	-1	-1	1	1	1	-1	*
16 -----++	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	*
17 -----++	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	*
18 -----++	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	1	*
19 -----++	-1	-1	-1	-1	-1	-1	1	-1	-1	1	-1	*
20 -----++	-1	-1	-1	-1	-1	-1	1	-1	-1	1	1	*
21 -----++	-1	-1	-1	-1	-1	-1	1	-1	1	-1	-1	*
22 -----++	-1	-1	-1	-1	-1	-1	1	-1	1	-1	1	*
23 -----++	-1	-1	-1	-1	-1	-1	1	1	-1	1	-1	*
24 -----++	-1	-1	-1	-1	-1	-1	1	1	-1	1	1	*
25 -----++	-1	-1	-1	-1	-1	-1	1	1	1	-1	-1	*
26 -----++	-1	-1	-1	-1	-1	-1	1	1	-1	-1	1	*
27 -----++	-1	-1	-1	-1	-1	-1	1	1	-1	1	-1	*
28 -----++	-1	-1	-1	-1	-1	-1	1	1	-1	1	1	*
29 -----++	-1	-1	-1	-1	-1	-1	1	1	1	-1	-1	*
30 -----++	-1	-1	-1	-1	-1	-1	1	1	1	-1	1	*

Deterministic Evaluation

You will be given a spreadsheet entitled “Calc_deterministic_Full_fact_tech”. This spreadsheet will take the above full factorial design and map the technology “k” factors to the metric RSEs generating deterministic results. The spreadsheet contains 5 sheets: “Full_Factorial”, “Results”, “k_factor_RSE”, “Check Compatibility”, and “Compatible List” (this one is needed for TOPSIS in step 8) as shown below. The “Full_Factorial” sheet is where you copy your full factorial design created in JMP. As you can see, the technologies are listed on the left and on the right are the “k” factors. The purpose of this spreadsheet is to map a specific technology to the “k” factor values, then convert the dimensional values to the non-dimensional form, feed those numbers into the “k_factor_RSE” and calculate the RSEs and copy the results back to the results sheet. As you see below, this sheet maps the technology to the individual “k” factors. For example, some of the equations contained in the cells under the “k” factors are provided below, including the wing weight, engine weight, and hydraulics weight. The conventional value for these “k” factors, i.e. no technology added, is “1” and 9238 for the engine weight. Hence, if the composite wing is “on”, e.g., \$B4=1, then add -0.2 to the wing weight value of 1, else, don’t add anything, “0”. And if the composite fuselage is “on”, e.g., \$C4=1, then add “0” to the wing weight value of 1, else, don’t add anything, “0”, etc. Of note, consider the engine weight equation. The conventional technology weight is 9,238 lbs. Now, if a technology is “on”, then the 9,238 lbs will change by a certain percentage as shown in the equation below. It is important to check that the equations match the “k” factors in the TIM. This spreadsheet is set up for 11 technologies and 16 “k” factors. If you have less than 11 technologies and 16 “k” factors, you need to modify the sheet. Also, if you have different technologies than the ones listed, you need to modify the spreadsheet. If you have no clue how to do this, just ask Dr. Kirby.

Wing weight:

$$=1+IF(\$B4=1,-0.2,0)+IF(\$C4=1,0,0)+IF(\$D4=1,0,0)+IF(\$E4=1,0.05,0)+IF(\$F4=1,0,0)+IF(\$G4=1,0,0)+IF(\$H4=1,0,0)+IF(\$I4=1,-0.1,0)+IF(\$J4=1,-0.05,0)+IF(\$K4=1,0.02,0)+IF(\$L4=1,0,0)$$

Engine weight:

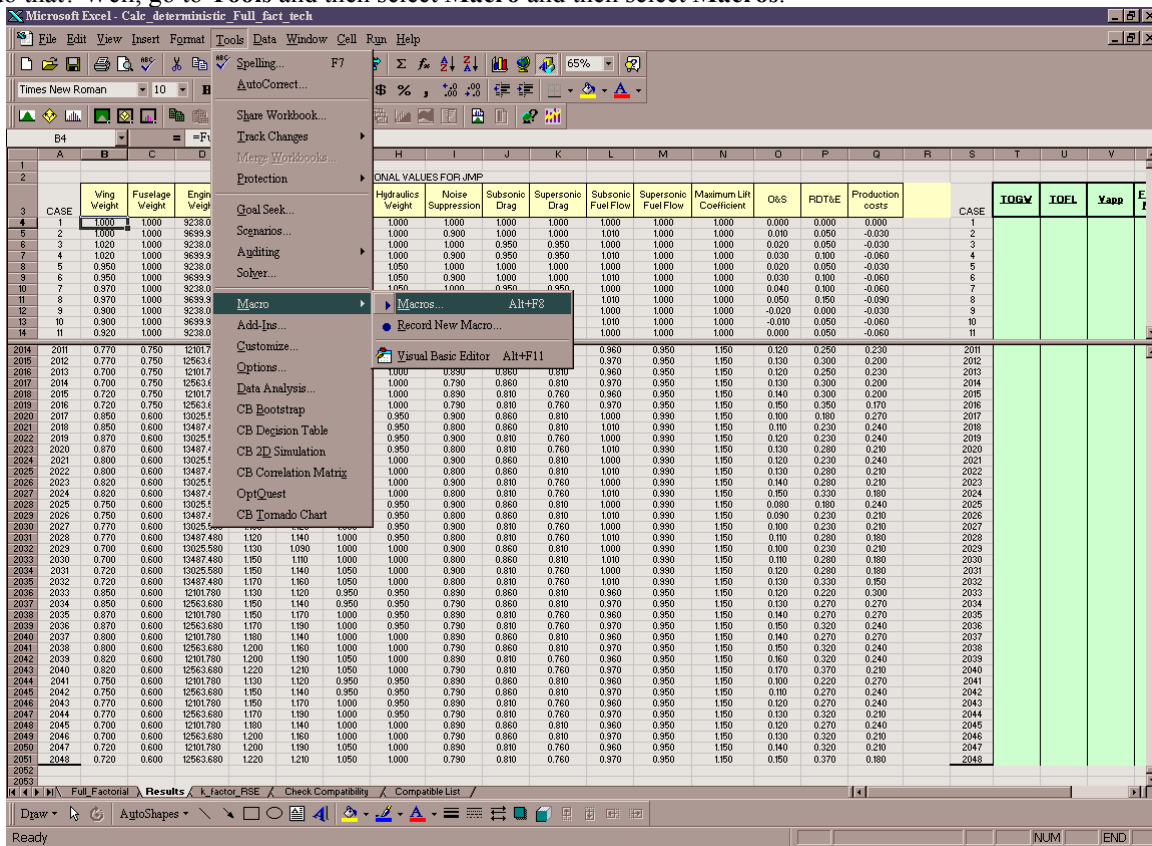
$$=(1+IF(\$B4=1,0,0)+IF(\$C4=1,0,0)+IF(\$D4=1,0,0)+IF(\$E4=1,0.01,0)+IF(\$F4=1,0.4,0)+IF(\$G4=1,0,0)+IF(\$H4=1,-0.1,0)+IF(\$I4=1,0,0)+IF(\$J4=1,0,0)+IF(\$K4=1,0,0)+IF(\$L4=1,0.05,0))*9238$$

Hydraulics weight:

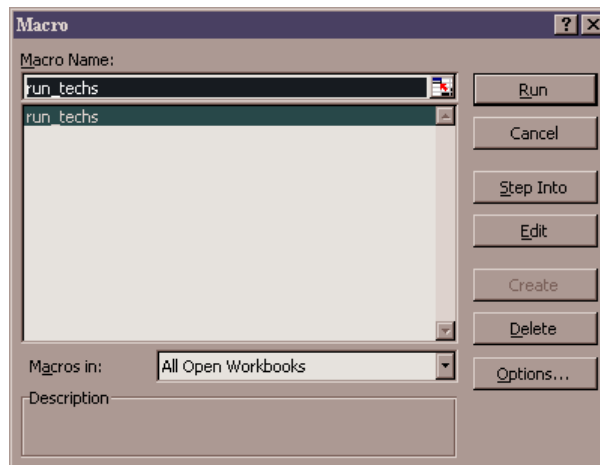
$$=1+IF(\$B4=1,0,0)+IF(\$C4=1,0,0)+IF(\$D4=1,-0.05,0)+IF(\$E4=1,0,0)+IF(\$F4=1,0,0)+IF(\$G4=1,0,0)+IF(\$H4=1,0,0)+IF(\$I4=1,0,0)+IF(\$J4=1,0.05,0)+IF(\$K4=1,0,0)+IF(\$L4=1,0,0)$$

The screenshot shows a Microsoft Excel spreadsheet titled "Calc_deterministic_Full_fact_tech". The spreadsheet is divided into several sections. The top section contains formulas for calculating Wing weight, Engine weight, and Hydraulics weight based on various technology factors (B4, C4, D4, E4, F4, G4, H4, I4, J4, K4, L4). The bottom section shows a table with columns for various technologies (Composite Wing, Composite Fuselage, Circulation Control, etc.) and rows for different aircraft configurations (1 through 53). The table contains 1s and -0.2s representing the technology factors.

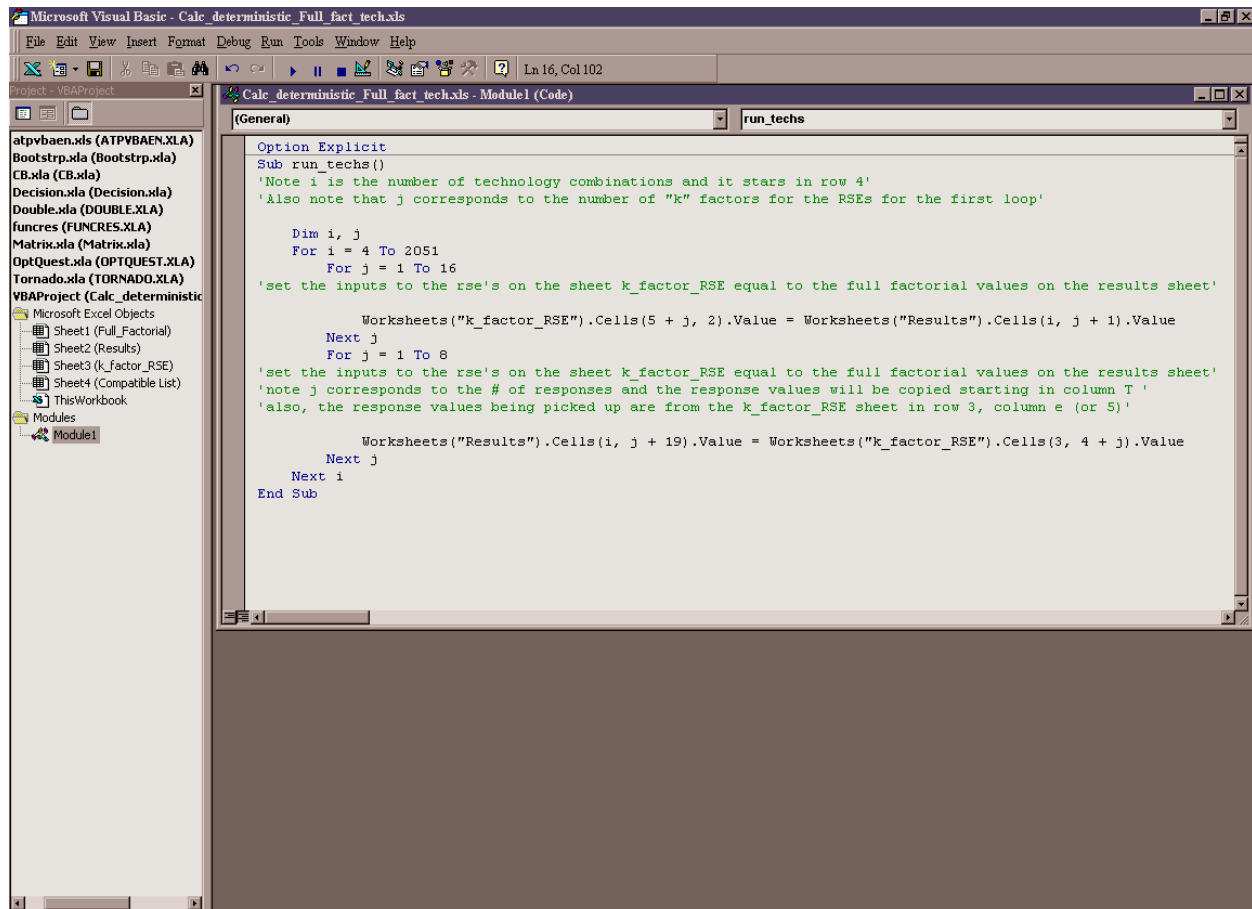
Now look at the sheet called “Results”. In cell B4, the info from translating the impact of a mix of technologies should be copied into these cells. If you look to the right, starting in column “T”, you will see where the responses are. At present, the response columns are empty since you haven’t actually calculated the RSEs. How might you do that? Well, go to **Tools** and then select **Macro** and then select **Macros**.



Then you will see the following window with the macro contained in this spreadsheet. It is entitled “run_techs”. Let’s take a look at what that macro does. Select “run_techs” if it is not highlighted and then select the **Edit** button.



Then the following window will pop up, if you have the Visual Basic Editor. The macro is commented as to what it is doing. There are a few hitches here. The macro is set up for 11 technologies for a full factorial evaluation (2,048 cases) and for 16 “k” factors and 8 responses. This is important due to where the cells are being referenced. For example, the list of the full factorial cases starts in row 4 and column 2 (or B4) on the sheet “Results”. Since there are 2,048 combination, the index “i” goes from 4 to 2,051. Next, the first occurrence of index “j” corresponds to the number of “k” factors and the second occurrence corresponds to the number of responses. Your response values must start in cell E3 on sheet “k_factor_RSE”. If they do not, you must modify the references in the macro. Also if you have more or less technologies, then you must change the index for “i”. Finally, if you have more or less “k” factors, then modify the value of the first occurrence of index “j” and if you have more or less responses, modify the second occurrence of index “j”. If you modify anything, then save the work and return to Excel.



Let's actually evaluate all of our technology combinations. Go back to **Tools** and then select **Macro** and then select **Macros** and now select **Run**. You will see that the cells underneath the responses to the right start to fill out. The macro will continue to run until it has evaluated all the technology combinations that you provided.

Microsoft Excel - Calc_deterministic_Full_fact_tech

File Edit View Insert Format Tools Data Window Cell Run Help

Times New Roman 10 B I U L \$ % 65%

B4 =Full_FactorialN4

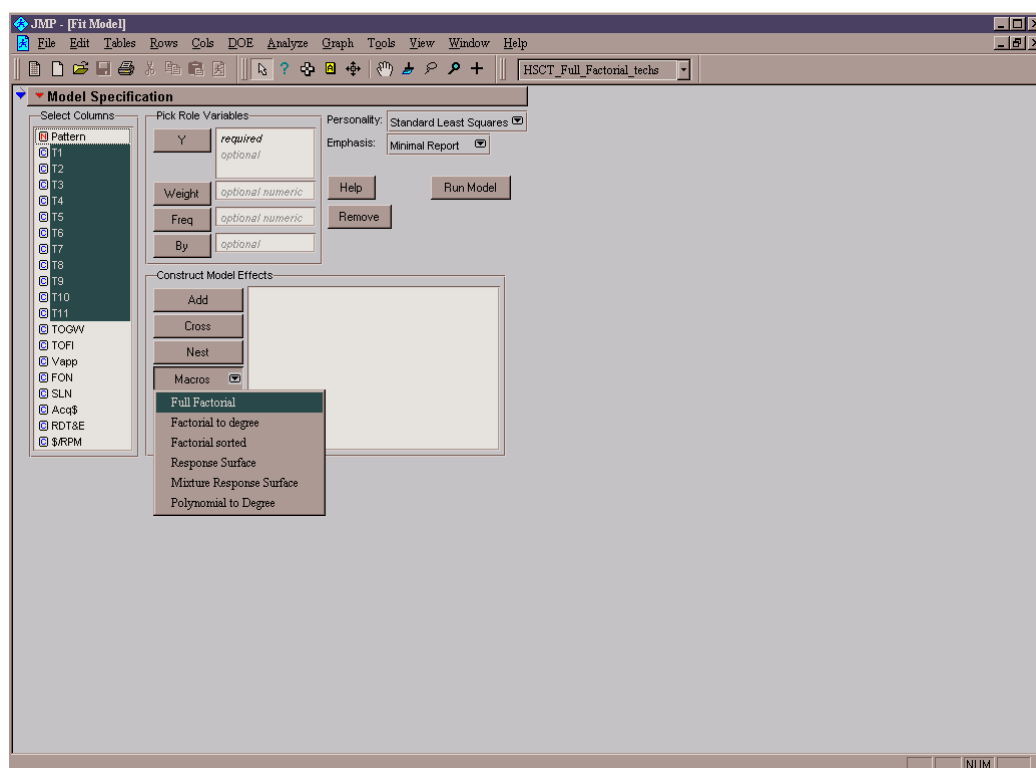
NONDIMENSIONAL VALUES FOR JUMP

CASE	Wing Weight	Fuselage Weight	Engine Weight	Electrical Weight	Avionics Weight	Surface Controls Weight	Hydraulics Weight	Noise Suppression	Subsonic Drag	Supersonic Drag	Subsonic Fuel Flow	Supersonic Fuel Flow	Maximum Lift Coefficient	O/S	PDtOE	Production costs	CASE	IOGW	IOEL	Yapp	E	
1	1.000	1.000	9238.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	1	895385.1	10707.03	95.385	1	
2	1.000	1.000	9699.900	1.020	1.020	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.010	0.050	-0.030	2	863626.0	10605.01	97.095	2	
3	1.020	1.000	9238.000	1.020	1.050	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.020	0.050	-0.020	3	824441	10331.5	93.357	3	
4	1.020	1.000	9699.900	1.040	1.070	1.050	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.030	0.100	-0.060	4	828225.1	10421.09	93.9652	4	
5	0.950	1.000	9238.000	1.050	1.020	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.020	0.050	-0.030	5	894422.3	10663.16	95.738	5	
6	0.950	1.000	9699.900	1.070	1.040	1.050	1.050	1.000	1.000	1.000	1.000	1.000	1.000	0.030	0.100	-0.060	6	859340.6	10753.99	95.6276	6	
7	0.970	1.000	9238.000	1.070	1.070	1.100	1.050	1.000	1.000	1.000	1.000	1.000	1.000	0.040	0.100	-0.060	7	88506.2	10276.31	92.7753	7	
8	0.970	1.000	9699.900	1.090	1.090	1.100	1.050	1.000	1.000	1.000	1.000	1.000	1.000	0.050	0.100	-0.090	8	823957.1	10356.35	93.3695	8	
9	0.900	1.000	9238.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-0.020	0.000	-0.030	9	836590.4	10495.24	94.6883	9	
10	0.900	1.000	9699.900	1.020	1.020	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-0.010	0.050	-0.060	10	844592.5	10566.85	95.334	10	
11	0.920	1.000	9238.000	1.020	1.050	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.050	-0.060	11	82318.9	10134.44	93.0165	11	
2004	2001	0.770	0.750	12917.780	1.130	1.150	1.000	0.950	0.890	0.810	0.760	0.960	0.950	1.150	0.120	0.250	0.230	2001				
2005	2002	0.770	0.750	12961.680	1.150	1.170	1.000	0.950	0.790	0.810	0.760	0.970	0.950	1.150	0.130	0.300	0.200	2002				
2006	2003	0.750	0.750	12917.780	1.130	1.150	1.000	0.950	0.890	0.810	0.760	0.960	0.950	1.150	0.120	0.250	0.230	2003				
2007	2004	0.700	0.750	12563.680	1.180	1.140	1.000	1.000	0.790	0.860	0.810	0.970	0.950	1.150	0.130	0.300	0.200	2004				
2008	2005	0.720	0.750	12917.780	1.180	1.170	1.000	0.950	0.810	0.810	0.760	0.960	0.950	1.150	0.140	0.300	0.200	2005				
2009	2006	0.720	0.750	12563.680	1.200	1.150	1.000	1.000	0.790	0.860	0.810	0.970	0.950	1.150	0.100	0.350	0.170	2006				
2010	2007	0.650	0.600	13025.580	1.080	1.070	0.950	0.950	0.900	0.860	0.810	1.000	0.990	1.150	0.100	0.180	0.270	2007				
2011	2008	0.650	0.600	13025.580	1.100	1.100	0.950	0.950	0.900	0.860	0.810	1.000	0.990	1.150	0.110	0.230	0.240	2008				
2012	2009	0.670	0.600	13025.580	1.100	1.120	1.000	0.950	0.900	0.810	0.760	1.000	0.990	1.150	0.120	0.230	0.240	2009				
2013	2010	0.670	0.600	13487.480	1.120	1.140	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.130	0.280	0.230	2010				
2014	2011	0.600	0.600	13025.580	1.130	1.090	1.000	0.950	0.800	0.860	0.810	1.000	0.990	1.150	0.120	0.230	0.240	2011				
2015	2012	0.600	0.600	13487.480	1.150	1.140	1.000	0.950	0.800	0.860	0.810	1.000	0.990	1.150	0.130	0.280	0.230	2012				
2016	2013	0.620	0.600	13025.580	1.150	1.140	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.140	0.280	0.230	2013				
2017	2014	0.620	0.600	13487.480	1.170	1.160	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.150	0.330	0.180	2014				
2018	2015	0.750	0.600	13025.580	1.080	1.070	0.950	0.950	0.900	0.860	0.810	1.000	0.990	1.150	0.080	0.180	0.240	2015				
2019	2016	0.750	0.600	13025.580	1.100	1.100	0.950	0.950	0.900	0.860	0.810	1.000	0.990	1.150	0.090	0.180	0.240	2016				
2020	2017	0.770	0.600	13025.580	1.100	1.120	1.000	0.950	0.900	0.810	0.760	1.000	0.990	1.150	0.100	0.230	0.230	2017				
2021	2018	0.770	0.600	13487.480	1.120	1.140	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.110	0.280	0.180	2018				
2022	2019	0.700	0.600	13025.580	1.130	1.090	1.000	0.950	0.800	0.860	0.810	1.000	0.990	1.150	0.120	0.230	0.240	2019				
2023	2020	0.700	0.600	13487.480	1.150	1.140	1.000	0.950	0.800	0.860	0.810	1.000	0.990	1.150	0.130	0.280	0.230	2020				
2024	2021	0.720	0.600	13025.580	1.150	1.140	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.140	0.280	0.230	2021				
2025	2022	0.620	0.600	13025.580	1.150	1.140	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.150	0.330	0.180	2022				
2026	2023	0.620	0.600	13487.480	1.170	1.160	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.160	0.380	0.130	2023				
2027	2024	0.650	0.600	13025.580	1.170	1.160	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.170	0.330	0.180	2024				
2028	2025	0.650	0.600	13487.480	1.190	1.180	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.180	0.380	0.130	2025				
2029	2026	0.700	0.600	13025.580	1.190	1.180	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.190	0.430	0.080	2026				
2030	2027	0.770	0.600	13025.580	1.190	1.200	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.200	0.480	0.030	2027				
2031	2028	0.770	0.600	13487.480	1.210	1.200	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.210	0.530	0.000	2028				
2032	2029	0.700	0.600	13025.580	1.210	1.200	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.220	0.580	0.000	2029				
2033	2030	0.700	0.600	13487.480	1.230	1.220	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.230	0.630	0.000	2030				
2034	2031	0.720	0.600	13025.580	1.230	1.220	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.240	0.680	0.000	2031				
2035	2032	0.720	0.600	13487.480	1.250	1.240	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.250	0.730	0.000	2032				
2036	2033	0.650	0.600	13025.580	1.250	1.240	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.260	0.780	0.000	2033				
2037	2034	0.650	0.600	13487.480	1.270	1.260	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.270	0.830	0.000	2034				
2038	2035	0.670	0.600	13025.580	1.270	1.260	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.280	0.880	0.000	2035				
2039	2036	0.670	0.600	13487.480	1.290	1.280	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.290	0.930	0.000	2036				
2040	2037	0.600	0.600	13025.580	1.290	1.280	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.300	0.980	0.000	2037				
2041	2038	0.600	0.600	13487.480	1.310	1.300	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.310	1.030	0.000	2038				
2042	2039	0.620	0.600	13025.580	1.310	1.300	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.320	1.080	0.000	2039				
2043	2040	0.620	0.600	13487.480	1.330	1.320	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.330	1.130	0.000	2040				
2044	2041	0.750	0.600	13025.580	1.330	1.320	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.340	1.180	0.000	2041				
2045	2042	0.750	0.600	13487.480	1.350	1.340	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.350	1.230	0.000	2042				
2046	2043	0.770	0.600	13025.580	1.350	1.340	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.360	1.280	0.000	2043				
2047	2044	0.770	0.600	13487.480	1.370	1.360	1.000	0.950	0.800	0.810	0.760	1.000	0.990	1.150	0.370	1.330	0.000	2044				
2048	2045	0.700	0.600	13025.580	1.370																	

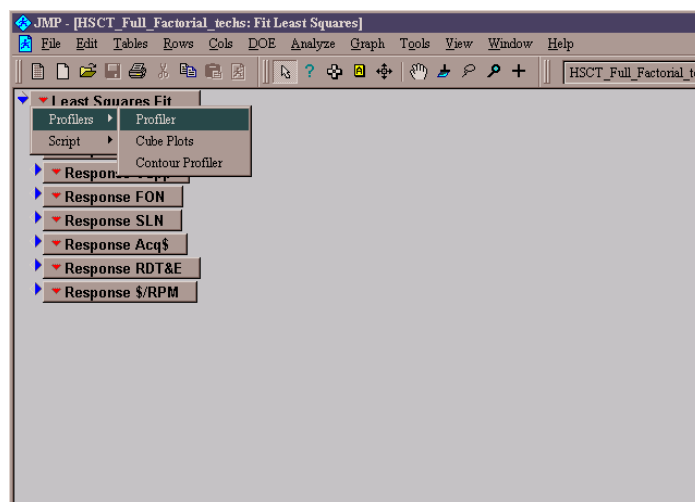
Now let's get a visual of how the sensitive the responses are to the technologies. To do so:

- Copy all of the values of the metrics as you have done so many times
- Open your full factorial JMP file
- Add the appropriate number of columns
- Paste your results

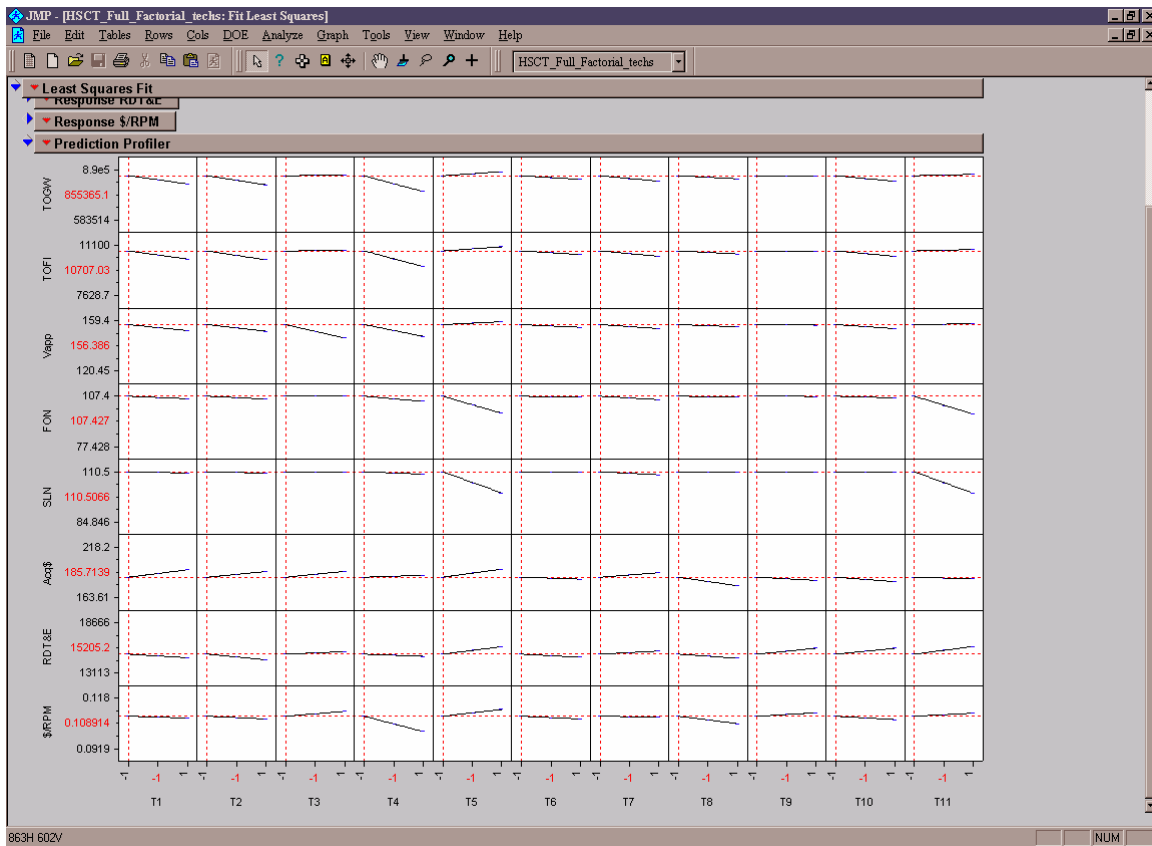
Then, go to **Analyze**, then **Fit Model**. When the **Fit Model** window comes up, select your technologies and then hit the **Macros** drop menu and select the **Full Factorial** option. The full factorial will fill out in the “Model Effects” window. Then select your responses and click the **Y** button. Don't forget turn off the “Center Polynomials” under the **Model Specification** drop menu. Once completed, hit **Run Model**.



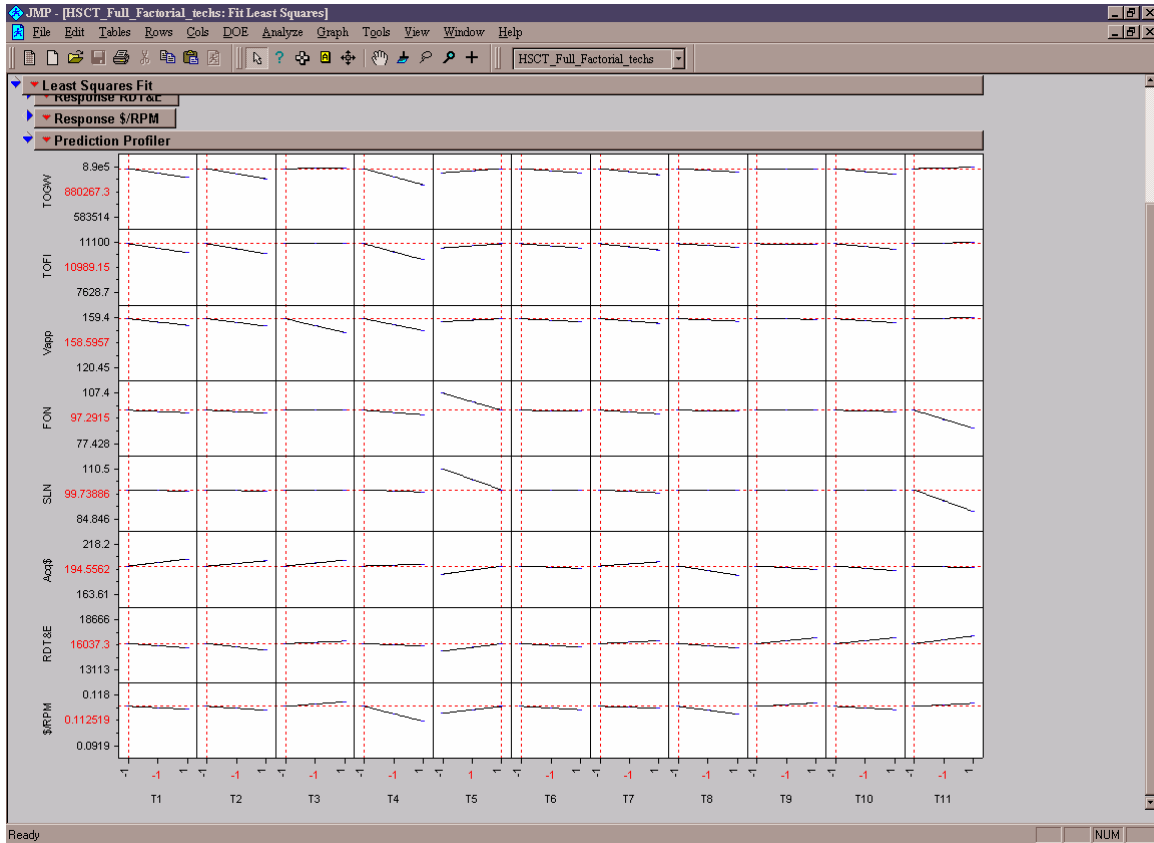
JMP will sit there for a bit while it is calculating all the statistics. Note, the more technologies you have, the longer it is going to take. Once JMP is finished, minimize all of the response analysis windows and open a Profiler.



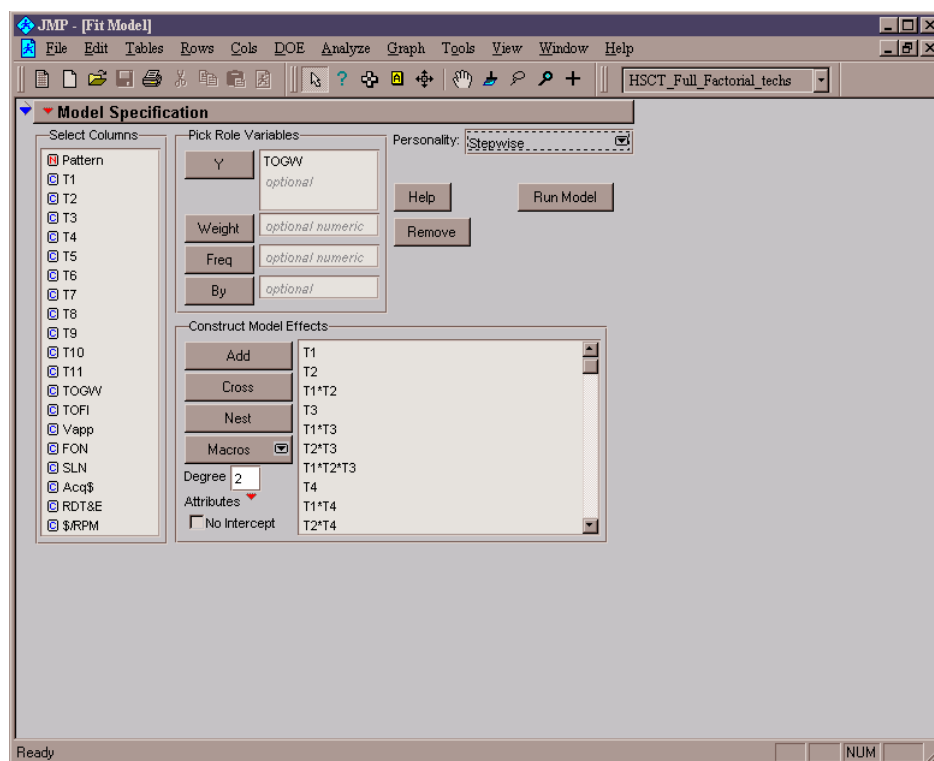
Again, if you have a lot of technologies, it is going to take JMP just a second to create the Profiler. Once the profiler is up, you now have a rapid environment whereby you can visualize the impact of ANY combination of technologies. As shown below. If you reset all of the technologies to a value of “-1”, this corresponds to all of the technologies being OFF. If you put any of the technologies to a value of “1”, then you will automatically update the values of the responses and see the impact that the chosen technology has on your system. Recall that all of the impacts to the system are inherent behind this profile. For each “-1” and “1” value in the full factorial DoE, you summed up all of the “k” factors and then calculated the RSEs. So, you are seeing the top level impact of all the “k” factors. You will never again have to run another code to determine the impact to your system from the set of technologies that you modeled. You can also determine if some combination of technologies will allow you to meet constraints by looking at the upper and lower bounds on your metrics.



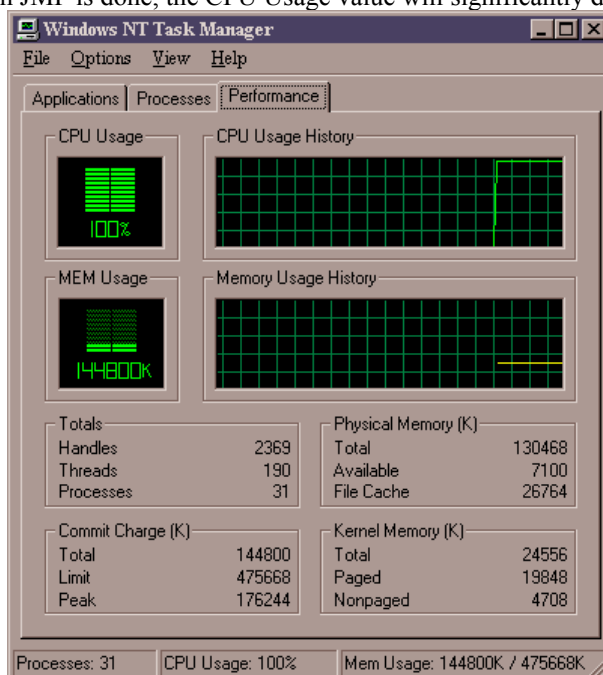
For example, Sideline Noise (or SLN) is a response with a constraint value of 103 EPNLdB. As you can see, once T5 is turned on, that constraint value can be met. Additionally, if you do not set a technology to a value of “1”, this is analogous to not getting the full impact from the technology that was described in the TIM. That is, if someone said that I am only getting 50% of what I was expecting from the technology, then you would set that technology value equal to “0” on the profile and read off the value of the responses. This is a poor man’s way of handling technological uncertainty or changing technological assumptions.



One way to get around the slowness of JMP creating the Prediction Profiler or the contour plot is to determine which interaction terms of the regressed coefficients do not need to be calculated. This is very important when you have a lot of technologies, or even with the RSEs if you have a lot of input variables. So, let's go through the steps of how you do that. Go back to your **Fit Model** window and only select one response, say TOGW. Now instead of selecting the "Standard Least Squares" option under the "Personality" drop menu, select the "Stepwise" option and then select **Run Model**.



JMP will take a while doing its thing. If you would like to know that it is still running, go to the Windows Task Manager as shown below. JMP will consume a great deal of CPU when it is running as you can see by the "CPU Usage" running at 100%. When JMP is done, the CPU Usage value will significantly drop.



When JMP is done, the window below will come up. JMP has the ability to determine which coefficients of the regressed response are the most significant contributors.

The screenshot shows the JMP Stepwise Fit window for the response variable TOGW. The 'Stepwise Regression Control' section has 'Prob to Enter' set to 0.250, 'Prob to Leave' set to 0.100, and 'Direction' set to 'Forward'. The 'Current Estimates' table is displayed below.

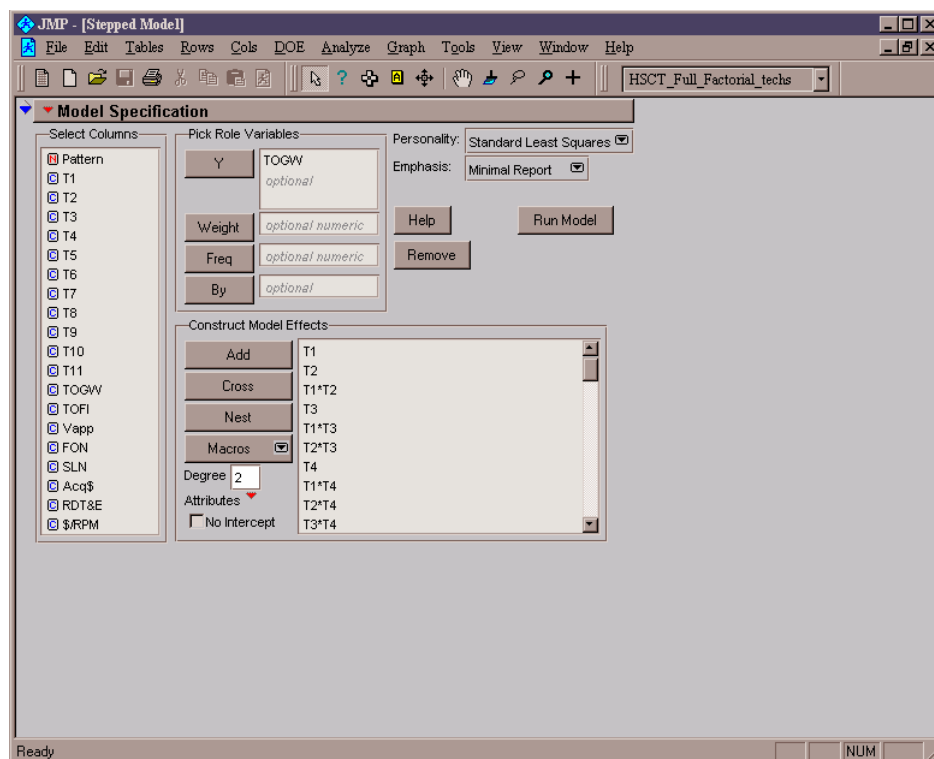
Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
		Intercept	718746.161	1	0	0.000	1.0000
		T1		1	8.073e11	207.434	0.0000
		T2		1	1.249e12	339.843	0.0000
		T1*T2		3	2.067e12	210.159	0.0000
		T3		1	30744726	0.007	0.9325
		T1*T3		3	8.074e11	69.089	0.0000
		T2*T3		3	1.249e12	113.183	0.0000
		T1*T2*T3		7	2.068e12	89.904	0.0000
		T4		1	5.316e12	3148.127	0.0000
		T1*T4		3	6.123e12	1576.044	0.0000
		T2*T4		3	6.565e12	2028.502	0.0000
		T1*T2*T4		7	7.384e12	1551.844	0.0000
		T3*T4		3	5.316e12	1048.508	0.0000
		T1*T3*T4		7	6.124e12	674.275	0.0000
		T2*T3*T4		7	6.565e12	867.869	0.0000
		T1*T2*T3*T4		15	7.384e12	721.662	0.0000
		T5		1	1.087e11	25.684	0.0000
		T1*T5		3	9.189e11	79.744	0.0000

To determine the coefficients, under the "Direction" drop menu, select "Mixed" and take the default values that JMP gives you and then hit **Go**. You will see check marks appearing in the "Entered" cells. Again look at your Task Manager and you will know when JMP is finished by the CPU Usage significantly dropping. When JMP is done, click the **Make Model** button.

The screenshot shows the JMP Stepwise Fit window for the response variable TOGW. The 'Stepwise Regression Control' section has 'Prob to Enter' set to 0.250, 'Prob to Leave' set to 0.250, and 'Direction' set to 'Mixed'. The 'Current Estimates' table is displayed below.

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
		Intercept	718746.161	1	0	0.000	1.0000
		T1	-19854.379	10	8.329e11	12920.61	0.0000
		T2	-24697.74	10	1.277e12	19802.74	0.0000
		T1*T2	2308.69851	2	1.092e10	846.662	0.0000
		T3		1	30744726	4.778	0.0289
		T1*T3		2	1.249e8	9.776	0.0001
		T2*T3		2	1.188e8	9.296	0.0001
		T1*T2*T3		4	2.130e8	8.385	0.0000
		T4	-50945.836	1	5.316e12	824561.2	0.0000
		T1*T4		1	2.527e8	39.967	0.0000
		T2*T4		1	3.072e8	48.783	0.0000
		T1*T2*T4		3	5.599e8	30.213	0.0000
		T3*T4		2	3.158e8	25.079	0.0000
		T1*T3*T4		5	6.627e8	21.614	0.0000
		T2*T3*T4		5	7.111e8	23.282	0.0000
		T1*T2*T3*T4		11	1.0581e9	16.156	0.0000
		T5	7286.31808	12	1.185e11	1531.248	0.0000
		T1*T5	-1185.7335	4	2.8794e9	111.666	0.0000

JMP will open a new **Fit Model** window with the chosen coefficient terms as shown below. Don't forget to turn off the "Center Polynomials" option under the **Model Specification** bar. If the "Emphasis" option is not on "Minimal Report" then select that option and click **Run Model**.



The window below will come up

Response TOGW

Summary of Fit

RSquare	0.999999
RSquare Adj	0.999999
Root Mean Square Error	64.11821
Mean of Response	718746.2
Observations (or Sum Wgts)	2048

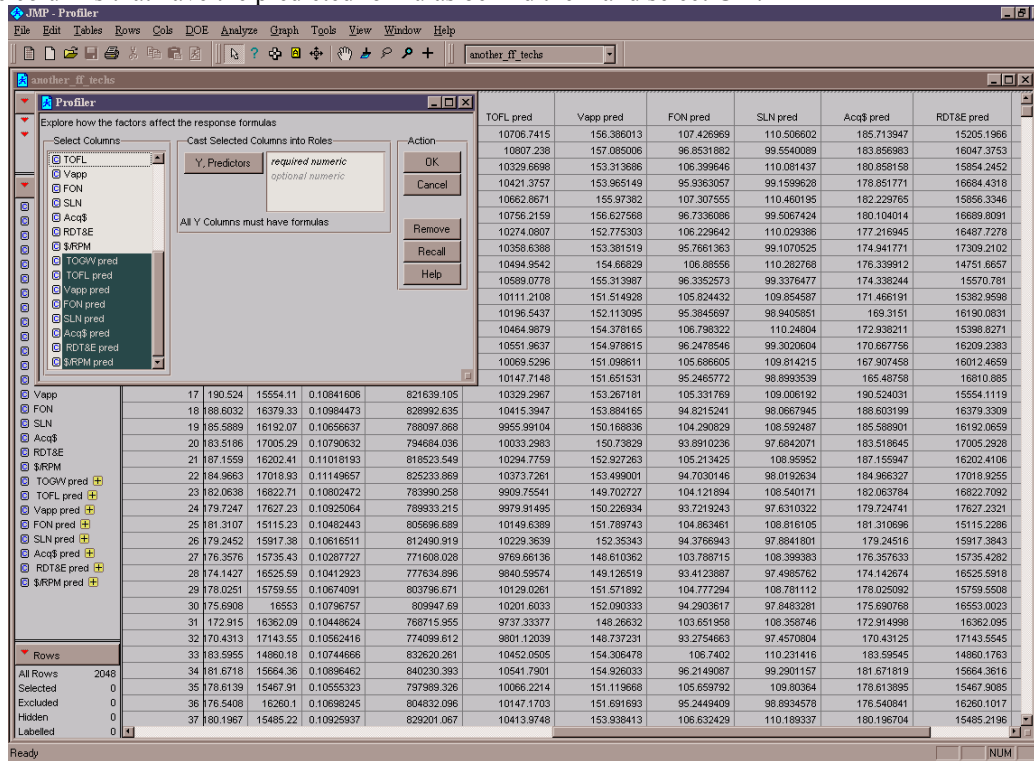
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	65	8.77015e12	1.3493e11	32619438	
Error	1982	8148288.21	4111.1444		
C. Total	2047	8.77016e12			0.0000

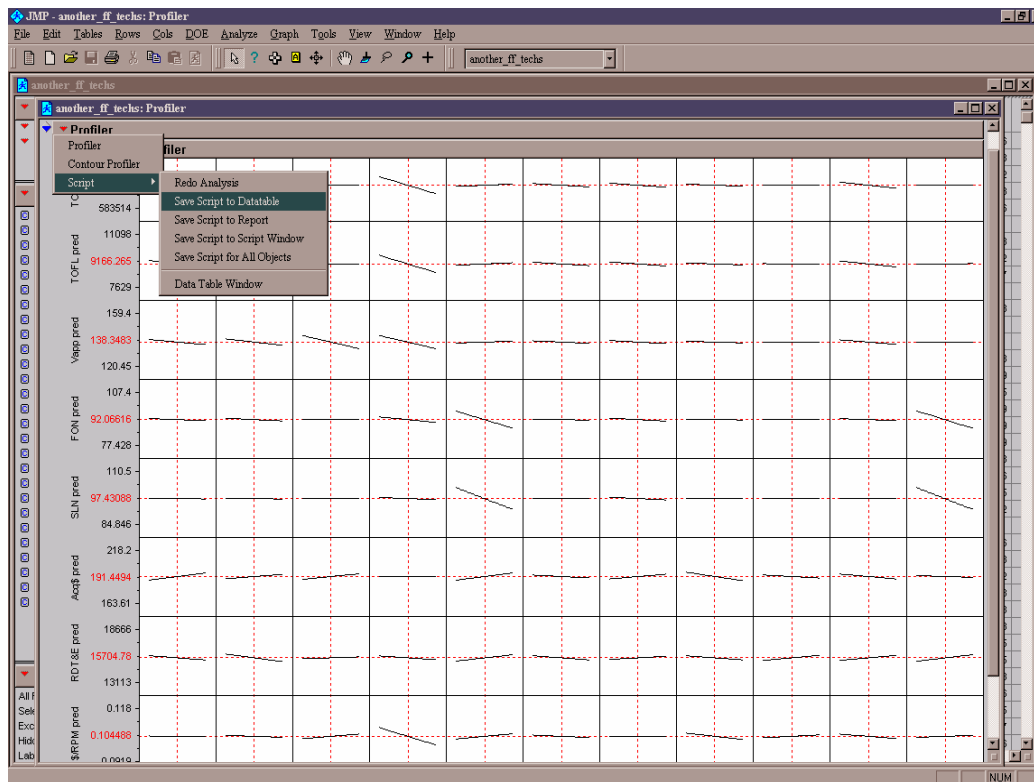
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	718746.16	1.416826	507293	0.0000
T1	-19854.38	1.416826	-14013	0.0000
T2	-24697.74	1.416826	-17432	0.0000
T1*T2	2308.6985	1.416826	1629.5	0.0000
T3	-122.5238	1.416826	-86.48	0.0000
T1*T3	-214.4729	1.416826	-151.4	0.0000
T2*T3	-207.4494	1.416826	-146.4	0.0000
T4	-50945.84	1.416826	-35958	0.0000
T1*T4	-351.3078	1.416826	-248	0.0000
T2*T4	-387.297	1.416826	-273.4	0.0000
T3*T4	-373.0762	1.416826	-263.3	0.0000
T5	7286.3181	1.416826	5142.7	0.0000
T1*T5	-1185.733	1.416826	-836.9	0.0000
T2*T5	-1525.925	1.416826	-1077	0.0000
T3*T5	-125.4492	1.416826	-88.54	0.0000
T4*T5	-284.4983	1.416826	-200.8	0.0000
T6	-9961.106	1.416826	-7e+3	0.0000

Repeat this process for every response that you have. Now, go to **Graph** and select the **Profiler**. Then select all of the columns that have the predicted formulas behind them and select **OK**.



Now, when the profiler comes up you can play technology games by turning on and off any technology you like. Also, under the **Profiler** drop menu, select the “Script” option and then select “Save Script to Databable”.



Go back to the JMP table and you will see “Profiler” has appeared in the top left corner. What this script does is automatically create the Profiler based on what you just did. To execute it, right mouse click on the “Profiler” and select **Run Script** and the profiler will automatically generate.

The screenshot shows the JMP software interface with a table named 'another_ft_techs'. The table has 11 columns: Acq\$, RDT&E, \$RPM, TOGW pred, TOFL pred, Vapp pred, FON pred, SLN pred, Acq\$ pred, and RDT&E pred. The table contains 2048 rows of data. A context menu is open over the 'another_ft_techs' table, showing options like 'Profile', 'Run Script', 'Edit', and 'Delete'. The 'Run Script' option is highlighted.

Populating the Decision Matrix

When you are finished with all the technology combinations, go back to Excel and to the “Compatible list” sheet. This sheet is again formatted for 11 technologies and 8 metrics. This sheet will automatically update from the values that were calculated on the “Results” sheet. On the right of this sheet is the determination of whether or not the technology mix (case #) is physically compatible or not. If the mix IS compatible, an “ok” is shown in the column. If not, then “XXXXXX” appears. A physically compatible combination is determined from the compatibility matrix and is coded as shown below for this example. You need to make sure that your mix of technologies is coded properly here. In addition, the column beside the one that determines compatibility is simply a counter. When the technology mix is compatible, a “1” results for the row, if not, then a “0”. At the bottom of the page is a summation to determine the number of physically compatible technology mixes. For this example, there are 272.

Example compatibility rule:

=IF(OR(AND(\$C4=1,\$F4=1),AND(\$C4=1,\$J4=1),AND(\$C4=1,\$K4=1),AND(\$C4=1,\$L4=1),AND(\$C4=1,\$M4=1),AND(\$F4=1,\$J4=1),AND(\$F4=1,\$K4=1),AND(\$F4=1,\$L4=1),AND(\$G4=1,\$M4=1),AND(\$H4=1,\$K4=1),AND(\$I4=1,\$J4=1),AND(\$J4=1,\$K4=1)), "XXXXXX", "ok")

The concepts identified in Step 6 (i.e., only the compatible technology mixes) form the rows and the system metrics from the problem definition form the columns as shown below. The deterministic elements of the matrix are populated from the results obtained in Step 7 for each alternative and metric.

The screenshot shows a Microsoft Excel spreadsheet titled "Calc_deterministic_Full_fact_tech". The spreadsheet is a large matrix with rows representing different technology combinations and columns representing various system metrics. The columns are labeled: Case, Composite Wing, Composite Fuselage, Circulation Control, HJFC, Environmental Engines, Flight Deck Systems, Propulsion Materials, Ingress, Egress, Airframe, Breakdown (total), IDEL, Yrps, Egress, Noise, Awa, FOTIE, AFRE, and Physically Feasible (y/n, no/yes). The rows are numbered 1 through 272, representing different technology combinations. The spreadsheet also includes a "Deterministic Evaluations contained below" section and a "Compatible List" section.

Note since you evaluated your technologies deterministically, you actually have your Decision Matrix defined. It is the matrix defined by the "compatible" list of technologies and the corresponding metric values in the "Compatible List" sheet in the "Calc_deterministic_Full_fact_tech" spreadsheet. Let's create our Compatible list of technologies based on the full factorial. Place your cursor in cell B4 and select everything including the compatibility rules in Column W, as shown below.

The screenshot shows a Microsoft Excel spreadsheet titled "Calc_deterministic_Full_fact_tech". The spreadsheet is a large matrix with rows representing different technology combinations and columns representing various system metrics. The columns are labeled: Case, Composite Wing, Composite Fuselage, Circulation Control, HJFC, Environmental Engines, Flight Deck Systems, Propulsion Materials, Ingress, Egress, Airframe, Breakdown (total), IDEL, Yrps, Egress, Noise, Awa, FOTIE, AFRE, and Physically Feasible (y/n, no/yes). The rows are numbered 1 through 272, representing different technology combinations. The spreadsheet also includes a "Deterministic Evaluations contained below" section and a "Compatible List" section.

Probabilistic Technology Evaluation

All of the evaluation of the technologies so far has been deterministic. This assumes that the technologies will reach the maximum possible impact, the values found in the TIM. Since these technologies are not fully matured, there is a chance that the final outcome will be less than the value in the TIM. To account for this variation in final outcome, we can use probabilistic evaluation. The file “Prob_tech eval” will allow you to evaluate the impact of technologies probabilistically. This file contains the sheets “Definitions”, “Prob Analysis”, “Cases”, and “RSE”. There may also be response sheets (called R1, R2, etc.). If there are not, they will be created later. Go back to the “Compatible list” sheet in the “Calc_deterministic_Full_fact_tech” file. Copy the case numbers and technology indicators for the compatible cases.

Microsoft Excel - Calc_deterministic_Full_fact_tech

File Edit View Insert Format Tools Data Window Cell Run CETools Help

Times New Roman 10 B U % , 65%

Sheet1

Case Composite Wing Composite Fuselage Circulation Control HLFC Environmental Engines Flight Deck Systems Propulsion Materials Integrally Stiffened Aluminum Airframe Structures (wing) Smart Wing Structures (Active Aerodynamic Control) Active Flow Control Acoustic Control TOGW TOEL Yaw Elevator Sideslip AOA Roll Rate Pitch Rate Physically Feasible (col. no. 2)

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 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778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1041 1042 1043 1044 1045 1046 1047 1048 1049 1050 1051 1052 1053 1054 1055 1056 1057 1058 1059 1060 1061 1062 1063 1064 1065 1066 1067 1068 1069 1070 1071 1072 1073 1074 1075 1076 1077 1078 1079 1080 1081 1082 1083 1084 1085 1086 1087 1088 1089 1090 1091 1092 1093 1094 1095 1096 1097 1098 1099 1100 1101 1102 1103 1104 1105 1106 1107 1108 1109 1110 1111 1112 1113 1114 1115 1116 1117 1118 1119 1120 1121 1122 1123 1124 1125 1126 1127 1128 1129 1130 1131 1132 1133 1134 1135 1136 1137 1138 1139 1140 1141 1142 1143 1144 1145 1146 1147 1148 1149 1150 1151 1152 1153 1154 1155 1156 1157 1158 1159 1160 1161 1162 1163 1164 1165 1166 1167 1168 1169 1170 1171 1172 1173 1174 1175 1176 1177 1178 1179 1180 1181 1182 1183 1184 1185 1186 1187 1188 1189 1190 1191 1192 1193 1194 1195 1196 1197 1198 1199 1200 1201 1202 1203 1204 1205 1206 1207 1208 1209 1210 1211 1212 1213 1214 1215 1216 1217 1218 1219 1220 1221 1222 1223 1224 1225 1226 1227 1228 1229 1230 1231 1232 1233 1234 1235 1236 1237 1238 1239 1240 1241 1242 1243 1244 1245 1246 1247 1248 1249 1250 1251 1252 1253 1254 1255 1256 1257 1258 1259 1260 1261 1262 1263 1264 1265 1266 1267 1268 1269 1270 1271 1272 1273 1274 1275 1276 1277 1278 1279 1280 1281 1282 1283 1284 1285 1286 1287 1288 1289 1290 1291 1292 1293 1294 1295 1296 1297 1298 1299 1300 1301 1302 1303 1304 1305 1306 1307 1308 1309 1310 1311 1312 1313 1314 1315 1316 1317 1318 1319 1320 1321 1322 1323 1324 1325 1326 1327 1328 1329 1330 1331 1332 1333 1334 1335 1336 1337 1338 1339 1340 1341 1342 1343 1344 1345 1346 1347 1348 1349 1350 1351 1352 1353 1354 1355 1356 1357 1358 1359 1360 1361 1362 1363 1364 1365 1366 1367 1368 1369 1370 1371 1372 1373 1374 1375 1376 1377 1378 1379 1380 1381 1382 1383 1384 1385 1386 1387 1388 1389 1390 1391 1392 1393 1394 1395 1396 1397 1398 1399 1400 1401 1402 1403 1404 1405 1406 1407 1408 1409 1410 1411 1412 1413 1414 1415 1416 1417 1418 1419 1420 1421 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2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059 2060 2061 2062 2063 2064 2065 2066 2067 2068 2069 2070 2071 2072 2073 2074 2075 2076 2077 2078 2079 2080 2081 2082 2083 2084 2085 2086 2087 2088 2089 2090 2091 2092 2093 2094 2095 2096 2097 2098 2099 2100 2101 2102 2103 2104 2105 2106 2107 2108 2109 2110 2111 2112 2113 2114 2115 2116 2117 2118 2119 2120 2121 2122 2123 2124 2125 2126 2127 2128 2129 2130 2131 2132 2133 2134 2135 2136 2137 2138 2139 2140 2141 2142 2143 2144 2145 2146 2147 2148 2149 2150 2151 2152 2153 2154 2155 2156 2157 2158 2159 2160 2161 2162 2163 2164 2165 2166 2167 2168 2169 2170 2171 2172 2173 2174 2175 2176 2177 2178 2179 2180 2181 2182 2183 2184 2185 2186 2187 2188 2189 2190 2191 2192 2193 2194 2195 2196 2197 2198 2199 2200 2201 2202 2203 2204 2205 2206 2207 2208 2209 2210 2211 2212 2213 2214 2215 2216 2217 2218 2219 2220 2221 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Bring your technology impact matrix into the “Prob Analysis” sheet. The ‘Probabilistic Scale’ matrix below the TIM will update automatically from the TIM and the TRLs. The scale is used in defining the distribution and follows the formula:

$$Scale = |(0.3 * impact) - (TRL - 1)| * \frac{|0.3 * impact| - |0.05 * impact|}{8}$$

If you have more technologies or “k” factors, you will need to expand both the TIM and the scale matrices. You must change all of the values in the technology impact matrix to negatives in order to run the simulation because you will use Weibull distributions to define each impact and this distribution must have a negative reference. The Weibull distribution is used because it best models the possible impacts of the technology by incorporating the TRL into the scale of the distribution.

Technology Impact Matrix (TIM)											
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Wing Weight	-0.2000			-0.0500				-0.1000	-0.0500	-0.0200	
Fuselage Weight		-0.2000				-0.1500					
Engine Weight				-0.0100	-0.4000		-0.1000				-0.0500
Electrical Weight			-0.0500	-0.0100			-0.0200	-0.0500		-0.0200	-0.0200
Avionics Weight				-0.0500			-0.0200	-0.0500		-0.0500	-0.0200
Surface Controls Weight			-0.0500						-0.0500	-0.0500	
Hydraulics Weight			-0.0500						-0.0500		
Noise Suppression					-0.1000		-0.0100				-0.1000
Subsonic Drag	-0.0200	-0.0200		-0.1000						-0.0200	
Supersonic Drag	-0.0200	-0.0200		-0.1500						-0.0500	
Subsonic Fuel Flow			-0.0100	-0.0100	-0.0200		-0.0400				-0.0100
Supersonic Fuel Flow				-0.0100	-0.0200		-0.0400				
Maximum Lift Coefficient			-0.1500								
CD2	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200		-0.0200	-0.0200	-0.0200	-0.0200	-0.0100
RDTE	-0.0400	-0.0400	-0.0200	-0.0200	-0.0400	-0.0200	-0.0400	-0.0500	-0.0500	-0.0500	-0.0500
Production costs	-0.0800	-0.0800	-0.0300	-0.0500	-0.0200	-0.0100	-0.0300	-0.0300	-0.0300	-0.0300	-0.0300
TRL	3	3	4	3	3	4	3	4	3	3	3

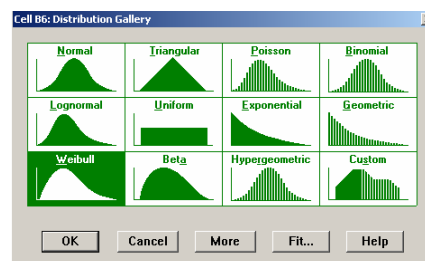
Probabilistic Scale											
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Wing Weight	0.0475	0	0	0.011875	0	0	0	0.020625	0.011875	0.00475	0
Fuselage Weight	0	0.059375	0	0	0	0.030938	0	0	0	0	0
Engine Weight	0	0	0	0.002375	0.095	0	0.02375	0	0	0	0.011875
Electrical Weight	0	0	0.010313	0.002375	0	0.004125	0.011875	0	0.00475	0.00475	0.00475
Avionics Weight	0	0	0	0.011875	0	0.004125	0.011875	0	0.011875	0.011875	0.00475
Surface Controls Weight	0	0	0.010313	0	0	0	0	0	0.011875	0.011875	0
Hydraulics Weight	0	0	0.010313	0	0	0	0	0	0.011875	0	0
Noise Suppression	0	0	0	0	0	0.002375	0.002375	0	0	0	0.02375
Subsonic Drag	0.00475	0.00475	0	0.02375	0	0	0	0	0	0.011875	0
Supersonic Drag	0.00475	0.00475	0	0.035625	0	0	0	0	0	0.011875	0
Subsonic Fuel Flow	0	0	0.002063	0.002375	0.00475	0	0.0095	0	0	0	0.002375
Supersonic Fuel Flow	0	0	0	0.002375	0.00475	0	0.0095	0	0	0	0
Maximum Lift Coefficient	0	0	0.030938	0	0	0	0	0	0	0	0
CD2	0.00475	0.00475	0.004125	0.00475	0.00475	0.00475	0.004125	0.00475	0.00475	0.002375	0.002375

All of these must be negative.

TRL Levels

“Probabilistic Scale” matrix

To define these distributions, highlight all of the cells in the TIM that contain influences (shown in green above). Click on the **Cell** menu, then **Define Assumptions**. This menu will pop up:



Select **Weibull** and then **OK**.

In the next menu, you should rename your assumption. Then check that the location and left bound are the impact from your TIM. The shape should be two and the right bound should be ‘+Infinity’. The scale will come from the probabilistic scale matrix. The cell can be referenced by entering ‘=B27’ in the menu. The scale should remain static through the simulation. Repeat this as each pair of windows pops up. Be sure to reference the scale for that specific technology and “k” factor.

These are equal

This cell is referenced here

Cell B6: Weibull Distribution

Assumption Name: Wing Weight

Location: -0.2000

Scale: =B27

Shape: 2

OK Cancel Enter Gallery Correlate... Help

Technology Impact Matrix (TIM)

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Wing Weight	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Fuselage Weight	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Engine Weight	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Electrical Weight	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Avionics Weight	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Surface Controls Weight	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Hydraulics Weight	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Noise Suppression	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Subsonic Drag	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Supersonic Drag	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Subsonic Fuel Flow	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Supersonic Fuel Flow	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Maximum Lift Coefficient	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
O&S	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
RDT&E	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000
Production costs	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000	-0.2000

Probabilistic Scale

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Wing Weight	0.0475	0	0	0.011875	0	0	0	0.020625	0.011875	0.00475	0
Fuselage Weight	0	0.059375	0	0	0	0.030938	0	0	0	0	0
Engine Weight	0	0	0	0.002375	0.095	0	0.02375	0	0	0	0.011875
Electrical Weight	0	0.010313	0.002375	0	0.004125	0.011875	0	0.00475	0.00475	0.00475	0.00475
Avionics Weight	0	0	0.011875	0	0	0.004125	0.011875	0	0.011875	0.011875	0.00475
Surface Controls Weight	0	0	0.010313	0	0	0	0	0	0.011875	0.011875	0
Hydraulics Weight	0	0	0.010313	0	0	0	0	0	0.011875	0.011875	0
Noise Suppression	0	0	0	0	0.02375	0	0.02375	0	0	0	0.02375
Subsonic Drag	0.00475	0.00475	0	0.02375	0	0	0	0	0	0	0
Supersonic Drag	0.00475	0.00475	0	0.03625	0	0	0	0	0	0.011875	0
Subsonic Fuel Flow	0	0	0.002063	0.002375	0.00475	0	0.0095	0	0	0	0.002375
Supersonic Fuel Flow	0	0	0.002375	0.00475	0	0.0095	0	0	0	0	0
Maximum Lift Coefficient	0.00475	0.00475	0.004125	0.00475	0.00475	0	0.00475	0.004125	0.00475	0.00475	0.002375
O&S	0.00475	0.00475	0.004125	0.00475	0.00475	0	0.00475	0.004125	0.00475	0.00475	0.002375
RDT&E	0.00475	0.00475	0.004125	0.00475	0.00475	0	0.00475	0.004125	0.00475	0.00475	0.002375
Production costs	0.00475	0.00475	0.004125	0.00475	0.00475	0	0.00475	0.004125	0.00475	0.00475	0.002375

Now, go back to the “Cases” sheet. The cells that contain the normalized “k” factors must be updated. These are linked to the “Prob Analysis” sheets so they will change with the changing tech combinations and “k” factors distributions. This is where the negatives entered into the TIM must be corrected. If a value in the TIM was changed to be negative, add a negative before its reference in the equation in the appropriate “k” factor as shown below.

Any necessary negatives go here.

Wing Weight

Fuselage Weight

Engine Weight

Electrical Weight

Avionics Weight

Surface Controls Weight

Hydraulics Weight

Noise Suppression

Subsonic Drag

Supersonic Drag

Subsonic Fuel Flow

Supersonic Fuel Flow

Maximum Lift Coefficient

O&S

RDT&E

Production costs

-1 -1 -1

1 1 3238 1 1 1 1 1 1 1 1 1 1 0 0 0

Add in your RSE on the “RSE” sheet. The ‘actual values’ for the “k” factors must be linked to the “k” factor cells you just checked on the “Cases” sheet. The responses should be highlighted and defined as the forecasts under the Cell menu and Define Forecast.

These need to be linked to the “Cases” sheet

These are your forecast cells

Rename the forecasts.

Cell E3: Define Forecast

Forecast Name: **TOGW**

Units:

Initial Window Size: ☒ Small ☐ Large

☒ Show Window: ☐ While Running ☒ When Stopped

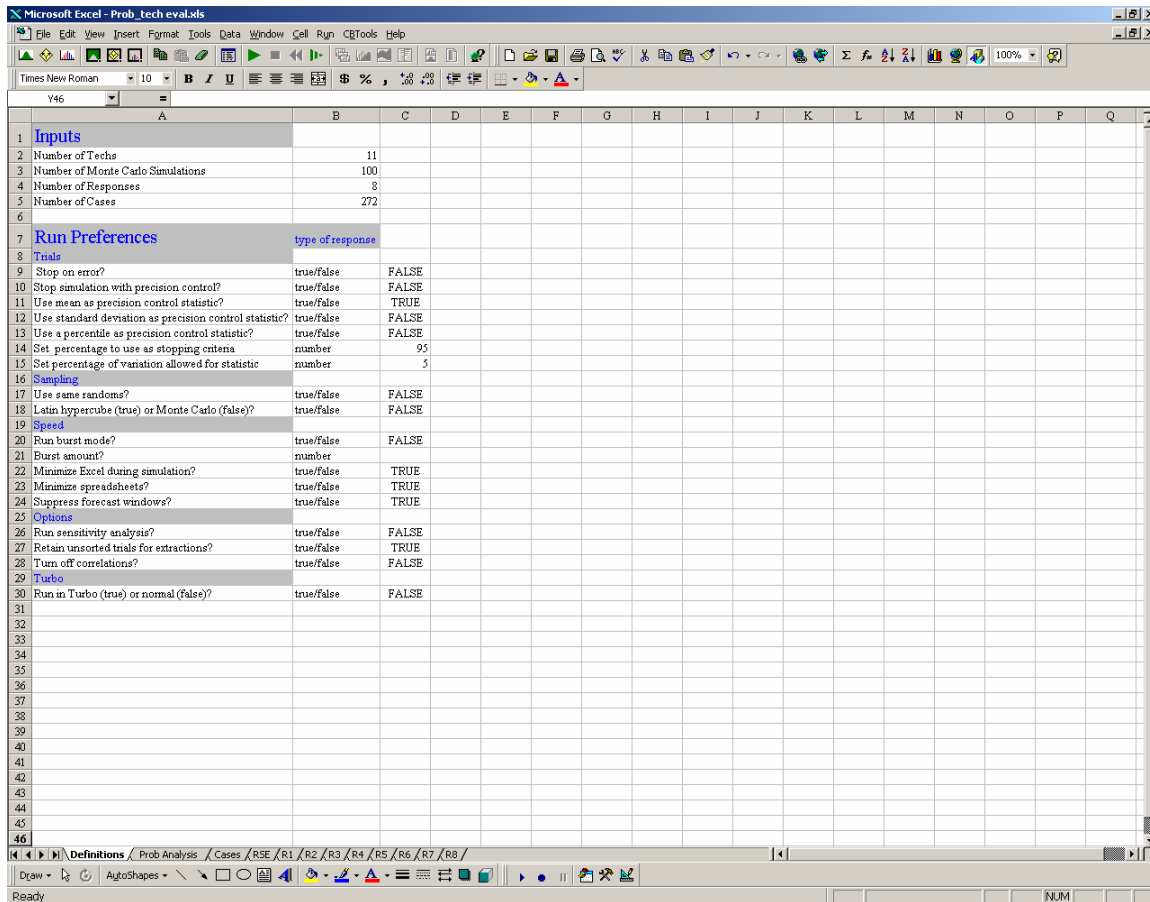
Window Precision Filter

OK Cancel Less << Set Default Help

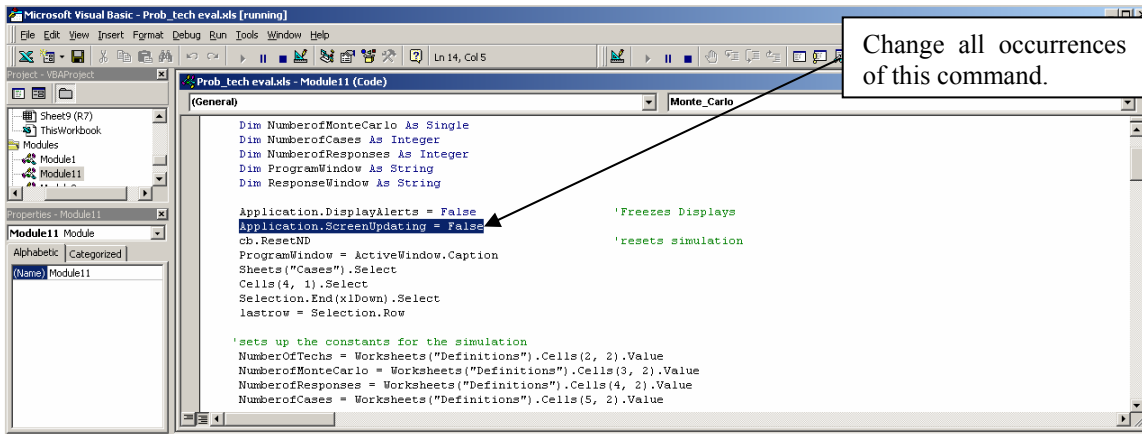
If this is not the response name, change it.

These do not matter this time because the forecast windows are suppressed by the macro.

The “Definitions” sheet defines the necessary information in order to run the macro to assess the different technology combinations probabilistically. The ‘Inputs’ reflect the number of technologies, how many Monte Carlo repetitions you want, how many responses, and how many cases. The ‘Run Preferences’ set the run preferences for the macro. The setup in this shot is the fastest way to run. Your computer’s Run Preferences will remain as set by the macro after it has completed. To change them, go to **Run, Run Preferences**. The Run Preferences will change to the preferences on the “Definitions” sheet every time you run the macro.



Unless you have changed sheet names, the macro should not require editing. Under **Tools**, choose **Macro**, then **Macros**. Select **Monte_Carlo** and **Run**. This macro will run Crystal Ball on each technology combinations. It extracts the percentiles and statistics and pastes them into the sheet for each response (R1 is the data for the first response and so on). If you want to see what it is doing, edit the macro and change all the Application.ScreenUpdating = False to true. This takes longer, but you can see each part of the macro.



A sheet for each response, numbered in the order of the RSE, has been created and filled by the macro. Your response sheets contain the percentiles and the statistics for each case.

The screenshot shows an Excel spreadsheet titled 'Prob_tech_evals'. The data is organized into columns for Case, Percentiles (0%, 5%, 10%, 15%, 20%, 25%), and various statistical measures (Total, Mean, Median, Mode, Standard Deviation, Variance, Skewness, Kurtosis, Coefficient of Variation). The data is presented in a grid format, with rows representing different cases and columns representing different statistical measures. The spreadsheet is filled with numerical data, and the layout is clean and professional.

These response sheets form a second decision matrix with probabilistic instead of deterministic results for each metric. Only compatible cases were brought in and evaluated so the cases do not need to be tested for compatibility as was done with the deterministic decision matrix. The probabilistic decision matrix will be used in step 8 to examine Technology Sensitivities and Technology Frontiers for different confidence levels.

Step 8: Select Best Family of Alternatives

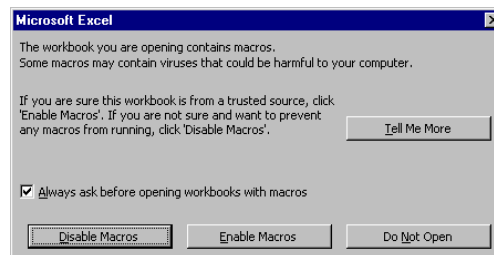
For any multi attribute, constraint, or criteria problem, the selection of the “best” family of alternatives is inherently subjective with no single answer fulfilling all requirements. Four techniques are used in the TIES method:

- 1) Multi-Attribute Decision-Making techniques (TOPSIS)
- 2) Technology Frontiers
- 3) Technology Sensitivities
- 4) Hierarchic Genetic Algorithms

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

A Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is utilized to down select the proper mix of technologies satisfying the system level metrics. TOPSIS provides a preference order of the deterministic values obtained in the Decision Matrix, at a given confidence level, resulting in a ranking of the best alternative concepts. I will not go through the math behind the TOPSIS method. You can go read one of the references to get more info. I will simply explain how you do it with the spreadsheets that I have provided.

If you have the HSCT with 11 technologies and the compatibility matrix from Step 6 of this tutorial, you have only 272 compatible combinations (or alternatives). You have obtained your response values of the vehicle with those technologies “on”. Open the Excel file “TOPSIS_tech_ranking”. The window below will come up, just click the button **Enable Macros**.



Regardless of which TOPSIS spreadsheet you have, there are 8 sheets including “Inputs”, “Scenarios”, “Alternatives List”, “Weighted_normalized_DM”, “Euclidean_dist”, “Rankings”, “Calc Area for Chart”, and “Radargram for subset”.

The first sheet is the “Inputs” sheet, but we will come back to it. On the next sheet, “Scenarios”, are 10 different subjective weighting scenarios. What I typically will do is place heavy weighting on the performance metrics on the left and shift to heavy economic weighting on the right. I tend to place more importance on the metrics that are the concept “show-stoppers”, or constraints that are hurting me most. In the sheet below, one scenario that I would consider is one that places heavy weighting on the Flyover and Sideline Noise metrics, since both of those had very low, if even existent, feasibility values. Hence, insert 10 or more different weighting scenarios depending on the metrics, the significance of each metric, and try to capture varying importance of the different metrics. The idea here is to determine if a given set of technology mixes will dominate in importance regardless of the weighting scenario considered.

Microsoft Excel - TOPSIS tech_ranking

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		Weighting Scenario									
		1	2	3	4	5	6	7	8	9	10
4	TOGW	0.100000	0.150	0.2	0.15	0.2	0.1	0.15	0.2	0.1	0.1
5	TOFL	0.200000	0.150	0.1	0.15	0.1	0.1	0.1	0.1	0.1	0.1
6	Vapp	0.100000	0.100	0.05	0	0.05	0.1	0.05	0.05	0.05	0.1
7	Flyover Noise	0.300000	0.200	0.05	0.15	0.05	0.4	0.1	0.05	0.05	0.1
8	Sideline Noise	0.300000	0.400	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2
9	Aca \$	0.000000	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
10	RDISE	0.000000	0	0.1	0	0.1	0.1	0.1	0.1	0.2	0.1
11	\$/RPM	0.000000	0	0.1	0.15	0.2	0.1	0.1	0.1	0.1	0.2
12	sum	1	1	1	1	1	1	1	1	1	1

Insert different weighting scenarios here

Ranking	1	2	3	4	5	6	7	8	9	10
1										
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Insert different alternative rankings here after you've gone through each sheet

Inputs Scenarios Alternatives List Weighted_normalized_DM Euclidean_dist Rankings Calc Area for Chart Radargram for subset

Draw AutoShapes

The “Alternatives List” sheet has the case numbers of the compatible technology combinations and the corresponding metric values for 8 metrics. You need to copy the metric values and case numbers into this sheet for all the compatible cases. You can copy these from the “Compatible list” sheet in the “Calc_deterministic_Full_fact_tech” file. As shown below, the square root of the sum of squares is calculated for each metric as the bottom of the page. The equation for this is shown for the TOGW below.

Example Excel formula for square root of sum of squares (TOGW):

$$=SQRT(SUMSQ(C\$4:C\$275))$$

This format is used for all metrics. Note, if you have more or less responses than the 8 given in the HSCT file, you need to modify ALL sheets that are dependent upon the number of response (i.e., attribute) columns.

Microsoft Excel - TOPSIS_tech_ranking

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
	Deterministic Evaluations contained below																					
	Number of Combinations	Case	TOGW	IOEL	Yapo	Fluoride Noise	Sidelane Noise	Aca	BDT&E	#BPM												
1	1	1	855365.08	10707.0306	156.38802	107.423863	105.703947	15205.18684	0.10831073													
2	2	1	863926.521	10805.0125	157.08502	96.853882	99.5540089	183.858383	0.10533331													
3	3	1	821441.033	10331.8954	153.3137	106.389646	100.6814374	180.8581582	0.10712676													
4	4	1	828235.113	10421.0885	153.38596	95.9363056	99.1596279	178.5057174	0.10856761													
5	5	1	858422.144	10663.1562	155.37353	107.307955	100.4601845	182.2372501	0.10958993													
6	6	1	859340.575	10753.5903	156.62758	96.7336086	99.50674239	180.1040141	0.11220468													
7	7	1	865066.243	10278.3062	152.77531	106.228642	110.0239863	177.289448	0.10860464													
8	8	1	823857.112	10358.3486	153.38953	95.7681363	99.1070247	174.9417707	0.11002146													
9	9	1	838590.405	10495.2434	154.6855	98.88956	102.2827677	176.3398921	0.10504479													
10	10	1	844982.549	10586.8523	155.314	96.3352573	99.33764768	174.3382444	0.10857637													
11	11	1	802188.938	10113.4383	151.51944	105.824432	108.8545888	171.4681932	0.10316035													
12	12	1	805353.717	10186.2545	152.1331	95.3845697	99.9403906	183.3953005	0.10460322													
13	13	1	828339.105	10323.5895	153.26717	105.331763	108.0818424	185.5240313	0.10948055													
14	14	1	828982.635	10413.1632	153.88415	94.825241	98.08679452	188.6031988	0.10984473													
15	15	1	788997.888	9958.21655	150.18882	104.298829	108.5324867	185.5889007	0.10566637													
16	16	20	794684.036	10033.0092	150.73828	97.890236	97.6842076	183.586449	0.10790632													
17	17	21	818523.548	10296.065	152.82725	105.213425	108.8589505	187.859467	0.11018683													
18	18	22	825233.869	10371.5006	153.48899	94.7030146	98.0926239	184.9663266	0.11496557													
19	19	23	783990.257	9911.98092	148.70272	104.121894	108.5401709	182.0637843	0.10802472													
20	20	24	789933.215	9978.62681	150.22832	93.7218243	97.830322	178.7247412	0.10925084													
21	21	25	832620.281	10452.3396	154.30649	96.7402	100.23146	180.07628	0.10744668													
22	22	26	840230.393	10539.5646	154.92605	96.2149088	99.29018585	181.6781891	0.10896462													
23	23	27	797889.326	10068.4469	151.18868	105.659792	109.8036398	178.6138949	0.10555322													
24	24	28	804832.096	10146.8882	151.8317	95.2444059	98.8324578	176.5406414	0.10636245													
25	25	29	818222.055	10257.3294	152.78974	106.281431	110.0348635	174.555488	0.1038585													
26	26	30	823272.887	10348.1815	153.366	95.7596175	99.1036311	172.4970836	0.1052886													
27	27	31	781043.686	9676.76482	148.53189	105.14728	109.6040708	183.565331	0.10186069													
28	28	32	787327.168	9848.82627	150.05062	94.7558445	98.7018174	187.3481738	0.10320182													
29	29	33	800688.484	10120.7262	151.63177	104.777425	108.7881561	186.8709102	0.10742412													
30	30	34	800300.715	10201.5526	152.14131	94.356887	97.85805287	186.6834907	0.10875178													
31	31	35	783440.368	9748.53943	148.39094	103.683399	108.3688407	183.6100935	0.10546887													
32	32	36	775075.228	9812.63097	148.88095	93.3328629	97.47285378	181.4737109	0.10676689													
33	33	37	800287.333	10089.1534	151.59565	97.2890077	99.7388223	184.9562368	0.11251886													
34	34	38	845961.309	10610.1454	155.52944	96.3952601	99.34681895	189.571895	0.11078948													
35	35	39	876411.584	10946.5535	158.2071	97.1757896	99.63428057	190.9424705	0.11431779													
36	36	71	841103.505	10555.8307	155.01455	96.2285563	99.2859046	185.8019563	0.11238069													
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The next sheet is the “Weighted_normalized_DM”. Two things are done on this sheet. First, the decision matrix is normalized and multiplied by the subjective weighting values defined by you. It is updated automatically from the alternatives sheet. It is found with this equation:

$$=(\text{'alternatives list'! original value/alternatives list! sum-of-squares}) * \text{weighting value}$$

Next the positive ideal and negative ideal solutions are determined for each metric. These are at the bottom of the matrix and are determined based on the following equations. For both TOPSIS spreadsheets provided, all the metrics are desired to be minimized, i.e., in the context of TOPSIS, they are considered “costs”. If you want to maximize a metric, it is considered a “benefit”. So, the Excel formulas used to determine the positive and negative ideal solutions are:

If you want to minimize your metrics, say TOGW, the ideal solutions are defined as:

Positive Ideal Solution, $S^+ = \text{MIN}(C5:C276)$

Negative Ideal Solution, $S^- = \text{MAX}(C5:C276)$

If you want to maximize your metrics, say TOGW, the ideal solutions would be defined as:

Positive Ideal Solution, $S^+ = \text{MAX}(C5:C276)$

Negative Ideal Solution, $S^- = \text{MIN}(C5:C276)$

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Below is the weighted normalized decision matrix. It is created by multiplying each cell from the results on the normalized_DM worksheet by the weighting factor of a given attribute row.

Metric (or attribute) weighting factors

Weighted normalized alternative metric values

Case	TOGW	TOPL	Vapp	Finger Noise	Sideline Noise	Ac 4	BDTAE	#RPM
1	0.00635	0.00659	0.00659	0.00668	0.01312	0.00585	0.00589	0.01225
2	0.00672	0.00685	0.00681	0.00690	0.01362	0.00579	0.00621	0.01243
3	0.00639	0.00636	0.00645	0.00659	0.01307	0.00570	0.00614	0.01205
4	0.00645	0.00642	0.00640	0.00655	0.01377	0.00563	0.00646	0.01222
5	0.00662	0.00667	0.00666	0.00685	0.01331	0.00574	0.00614	0.01245
6	0.00668	0.00662	0.00659	0.00690	0.01381	0.00567	0.00646	0.01262
7	0.00635	0.00633	0.00645	0.00659	0.01308	0.00565	0.00639	0.01221
8	0.00641	0.00638	0.00645	0.00654	0.01376	0.00551	0.00670	0.01237
9	0.00651	0.00646	0.00651	0.00662	0.01309	0.00555	0.00571	0.01181
10	0.00657	0.00652	0.00653	0.00657	0.01379	0.00549	0.00603	0.01189
11	0.00624	0.00623	0.00637	0.00656	0.01304	0.00540	0.00596	0.01180
12	0.00630	0.00628	0.00640	0.00651	0.01375	0.00532	0.00627	0.01176
13	0.00639	0.00638	0.00645	0.00653	0.01324	0.00560	0.00602	0.01219
14	0.00645	0.00641	0.00647	0.00658	0.01384	0.00534	0.00634	0.01235
15	0.00613	0.00615	0.00622	0.00646	0.01339	0.00539	0.00627	0.01193
16	0.00616	0.00618	0.00634	0.00652	0.01360	0.00579	0.00559	0.01213
17	0.00637	0.00634	0.00643	0.00652	0.01333	0.00590	0.00627	0.01239
18	0.00642	0.00638	0.00642	0.00657	0.01384	0.00563	0.00593	0.01244
19	0.00630	0.00630	0.00630	0.00645	0.01388	0.00574	0.00591	0.01215
20	0.00614	0.00615	0.00632	0.00651	0.01359	0.00566	0.00583	0.01229
21	0.00640	0.00644	0.00649	0.00662	0.01309	0.00579	0.00575	0.01208
22	0.00654	0.00649	0.00652	0.00656	0.01379	0.00572	0.00607	0.01225
23	0.00621	0.00620	0.00636	0.00655	0.01303	0.00563	0.00599	0.01187
24	0.00626	0.00625	0.00638	0.00650	0.01374	0.00556	0.00630	0.01203
25	0.00635	0.00632	0.00643	0.00659	0.01306	0.00550	0.00559	0.01186
26	0.00640	0.00637	0.00645	0.00653	0.01376	0.00543	0.00598	0.01184
27	0.00608	0.00608	0.00629	0.00652	0.01301	0.00534	0.00581	0.01145
28	0.00612	0.00615	0.00631	0.00657	0.01372	0.00527	0.00601	0.01181
29	0.00625	0.00624	0.00638	0.00649	0.01321	0.00534	0.00590	0.01208
30	0.00630	0.00628	0.00640	0.00655	0.01362	0.00588	0.00620	0.01223
31	0.00659	0.00650	0.00624	0.00643	0.01326	0.00579	0.00612	0.01186
32	0.00603	0.00604	0.00626	0.00678	0.01357	0.00572	0.00643	0.01200
33	0.00605	0.00617	0.00667	0.00663	0.01384	0.00613	0.00621	0.01255
34	0.00650	0.00655	0.00654	0.00597	0.01379	0.00597	0.00646	0.01246
35	0.00682	0.00674	0.00666	0.00602	0.01383	0.00601	0.00646	0.01286
36	0.00654	0.00650	0.00652	0.00596	0.01379	0.00595	0.00671	0.01263
37	0.00669	0.00662	0.00659	0.00600	0.01381	0.00582	0.00602	0.01219
38	0.00642	0.00639	0.00646	0.00594	0.01377	0.00566	0.00627	0.01196
39	0.00656	0.00651	0.00653	0.00590	0.01366	0.00627	0.00633	0.01255
40	0.00629	0.00628	0.00640	0.00594	0.01381	0.00611	0.00598	0.01235
41	0.00653	0.00649	0.00651	0.00599	0.01385	0.00616	0.00559	0.01275
42	0.00626	0.00625	0.00638	0.00583	0.01381	0.00600	0.00603	0.01251
43	0.00685	0.00659	0.00657	0.00599	0.01381	0.00605	0.00606	0.01245
44	0.00639	0.00638	0.00644	0.00593	0.01376	0.00589	0.00629	0.01225
45	0.00651	0.00646	0.00650	0.00596	0.01379	0.00575	0.00588	0.01202
46	0.00623	0.00622	0.00637	0.00590	0.01373	0.00559	0.00610	0.01196
47	0.00632	0.00630	0.00647	0.00647	0.01388	0.00646	0.00559	0.01224
48	0.00676	0.00678	0.00671	0.00637	0.01382	0.00644	0.00573	0.01242
49	0.00678	0.00681	0.00671	0.00643	0.01386	0.00636	0.00644	0.01222
50	0.00696	0.00670	0.00666	0.00634	0.01390	0.00644	0.00559	0.01236
51	0.00603	0.00602	0.00593	0.00585	0.01370	0.00671	0.00584	0.01261
52	0.00654	0.00596	0.00574	0.00574	0.01384	0.00687	0.00597	0.01254
53	0.00698	0.00598	0.00575	0.00581	0.01387	0.00659	0.00567	0.01246
54	0.00671	0.00575	0.00563	0.00571	0.01352	0.00677	0.00591	0.01254
55	0.00651	0.00621	0.00638	0.00596	0.01343	0.00527	0.00634	0.01195
56	0.00687	0.00677	0.00667	0.00666	0.01312	0.00687	0.00632	0.01313

Note for minimizing objectives, the positive ideal solution for THAT

The next sheet is the “Euclidean_dist” sheet. This sheet determines the separation from the positive and negative ideal solutions and calculated by the difference of the sum of squares of the weighted decision matrix and the positive ideal solution and negative ideal solutions, respectively. Examples of these two calculations are provided. In addition, the relative closeness to the Ideal Solution is determined. You will use these values for the alternative rankings. An example of how this is calculated is also provided.

Example formula for the Separation from the Positive Ideal Solution:

=SQRT(SUMXMY2(Weighted_normalized_DM!C5:J5,Weighted_normalized_DM!C\$277:J\$277))

Example formula for the Separation from the Negative Ideal Solution:

=SQRT(SUMXMY2(Weighted_normalized_DM!C5:J5,Weighted_normalized_DM!C\$278:J\$278))

Example formula for calculating the Relative Closeness to the Ideal solution:

=E4/(E4+C4)

Remember, if you have a different number of cases or metrics, you need to modify the cell referencing.

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Below is the separation from the positive ideal solution and calculated by the difference of the sum of squares of the weighted decision matrix and the positive ideal solution.

Case	Separation from Positive Ideal	Separation from Negative Ideal	Relative Closeness to Ideal Solution	Case
1	0.003483	0.00724	0.3307712	1
2	0.003325	0.002090	0.38932967	2
3	0.003147	0.001902	0.37693271	3
4	0.002782	0.002291	0.45968221	4
5	0.002560	0.002579	0.30893332	5
6	0.002440	0.002031	0.38532684	6
7	0.002325	0.002624	0.36123306	7
8	0.002099	0.002230	0.44181671	8
9	0.002010	0.002277	0.42266787	9
10	0.002063	0.002534	0.46767256	10
11	0.002780	0.002496	0.47306208	11
12	0.002314	0.002786	0.54628543	12
13	0.002784	0.002784	0.35201934	13
14	0.002832	0.002225	0.440952402	14
15	0.002828	0.001980	0.43025931	15
16	0.002516	0.002593	0.48851895	16
17	0.002442	0.001670	0.32632204	17
18	0.002969	0.002186	0.4245074	18
19	0.002928	0.001924	0.398524502	19
20	0.002599	0.002630	0.46957644	20
21	0.003194	0.001995	0.383259678	21
22	0.002776	0.002302	0.453277337	22
23	0.002847	0.002211	0.437180734	23
24	0.002408	0.002595	0.517475709	24
25	0.002872	0.002532	0.468569001	25
26	0.002359	0.002795	0.538760081	26
27	0.002537	0.002787	0.521729595	27
28	0.001889	0.002039	0.404376708	28
29	0.002410	0.001953	0.462070065	29
30	0.002548	0.002424	0.4874893	30
31	0.002593	0.002259	0.46853322	31
32	0.002209	0.002726	0.37862322	32
33	0.003453	0.001822	0.34546277	33
34	0.003100	0.001985	0.387874371	34
35	0.002569	0.001756	0.322946238	35
36	0.003217	0.001951	0.377506819	36
37	0.002934	0.002240	0.43293746	37
38	0.002105	0.002444	0.487527011	38
39	0.002810	0.002213	0.440575778	39
40	0.002465	0.002660	0.519008846	40
41	0.002172	0.002774	0.560828751	41
42	0.002230	0.002876	0.563250047	42
43	0.002825	0.002240	0.442003009	43
44	0.002764	0.002298	0.453983586	44
45	0.002616	0.002525	0.49185682	45
46	0.002603	0.002517	0.491850194	46
47	0.002633	0.002473	0.48436286	47
48	0.002635	0.002693	0.505432307	48
49	0.002328	0.002747	0.541244065	49
50	0.002401	0.002301	0.547132737	50

Separation from positive ideal solution

Relative closeness to ideal solution

Separation from negative ideal solution

The next sheet is “Rankings”. This sheet has columns for the ranking, case number, and the ‘relative closeness to ideal solution’ value, which is labeled ‘Ranked Order from Best to Worst’. The case number and ranked order columns should be blank until you run the macro.

Ranking	Case	Ranked Order from Best to Worst
1	674	0.61003546
2	590	0.80083826
3	930	0.78703086
4	946	0.76865287
5	737	0.75128352
6	753	0.74797322
7	659	0.744367247
8	642	0.737379795
9	993	0.724952065
10	178	0.723455906
11	1009	0.71873885
12	556	0.71820844
13	914	0.714784376
14	898	0.709934143
15	812	0.703835505
16	434	0.699462888
17	852	0.69380083
18	721	0.687084919
19	689	0.683469186
20	619	0.673305671
21	418	0.671827929
22	705	0.670860788
23	673	0.669552146
24	945	0.668384604
25	241	0.663004536
26	977	0.661462053
27	146	0.659567625
28	929	0.657253348
29	875	0.655773671
30	524	0.651624918
31	564	0.645499452
32	961	0.645289335
33	657	0.642320984
34	497	0.640054665
35	554	0.63775079
36	402	0.635186199
258	17	0.352801484
259	289	0.352105941
260	65	0.345462779
261	259	0.344061985
262	1	0.33107172
263	263	0.330819508
264	69	0.329746238
265	21	0.326332804
266	273	0.32494933
267	321	0.324253512
268	325	0.312419709
269	5	0.306093312
270	277	0.301022238
271	257	0.295612713
272	261	0.272194938

The last two sheets we'll talk about later. So, let's run the macro.

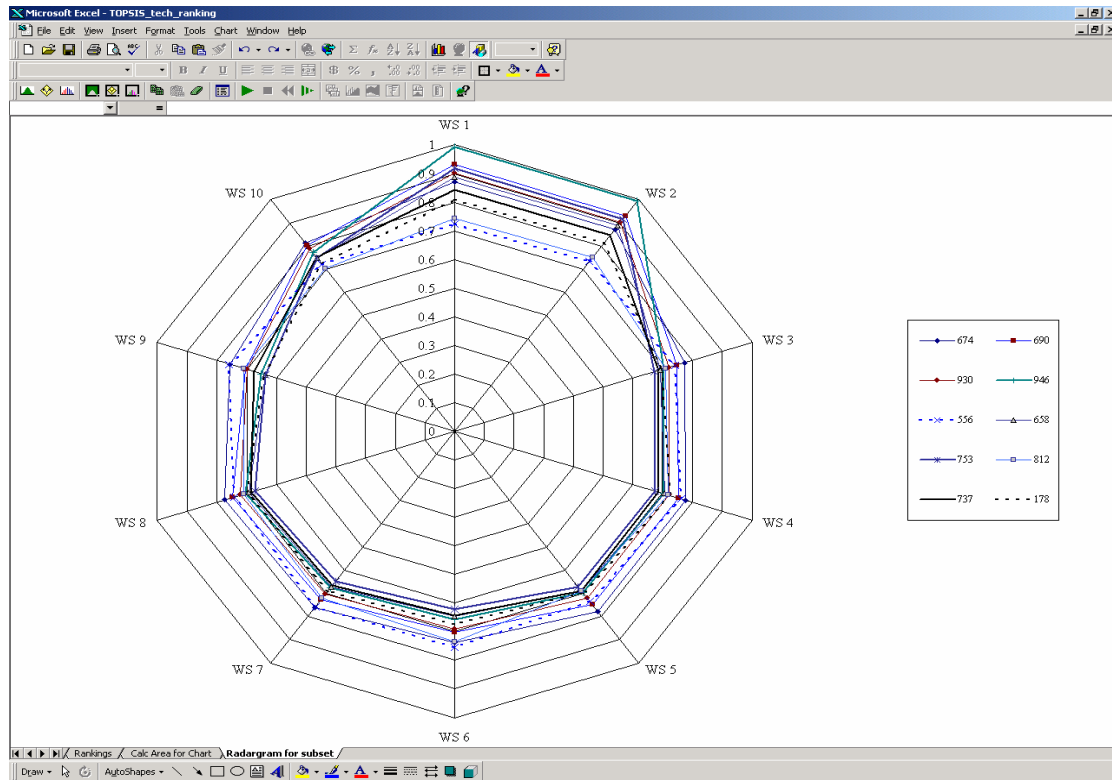
To evaluate the different weighing scenarios, you can run the “run_topsis” macro. In order to do this, you must fill in the “Inputs” sheet to reflect the number of technology combinations, responses, weighing scenarios, and top alternatives to extract. Then go to the **Tools** menu, select **Macro**, and then **Macros**. Select the “run_topsis” macro and hit **Run**.

The first thing the macro does is copy the weighting factors for the first scenario from the “Scenarios” sheet to the “Weighted_normalized_DM” sheet. The values for the weighted normalized responses automatically update. Then the values for the ‘Relative Closeness to Ideal Solution’, which also update automatically, are copied from the “Euclidean_distance” sheet and pasted to the “Rankings” sheet under the ‘Ranked Order from Best to Worst’ column and to the “Calc Area for Chart” sheet into the column for the first weighing scenario. The case numbers are then copied to the “Rankings” sheet in the ‘Case’ column. Next, the ‘Case’ and ‘Ranked Order from Best to Worst’ columns on the “Rankings” sheet are sorted in descending order by the ‘Ranked Order from Best to Worst’ column. Finally, the top 25 case numbers are pasted into the “Scenarios” sheet in the ‘Ranking’ column for the first scenario. This process is repeated for all the weighing scenarios.

The “Calc Area for Chart” sheet uses the relative closeness values to find a top ten overall. This page calculates area based on a ten spoke circle (based on ten weighing scenarios). It calculates the area, sums it, and uses this to rank its top ten combinations. These top ten are graphed, with their relative closeness values for each weighing scenario, on the last page, “Radargram for subset”. This graph should automatically update when the macro has been run. The “Calculated Area for Chart” sheet should look like this:

Case	WS 1	WS 2	WS 3	WS 4	WS 5	WS 6	Total Area	Case
674	0.87029362	0.870819818	0.772324164	0.77672383	0.778006125	0.7373712177	0.966015151	674
690	0.930078049	0.928889485	0.745356706	0.751796066	0.747242111	0.700624376	0.939355965	690
930	0.90046607	0.901073741	0.721492124	0.720456811	0.720415268	0.690330589	0.887869779	930
946	0.990841279	0.990763868	0.699998406	0.701690769	0.695513362	0.657886447	0.887698137	946
556	0.722613984	0.730063434	0.738700873	0.728300662	0.731016774	0.752725318	0.848084032	556
658	0.88694591	0.88762374	0.689733852	0.702268299	0.68945774	0.64464061	0.87474781	658
753	0.915825346	0.915230027	0.670806366	0.672292169	0.669289344	0.619128622	0.801168095	753
812	0.743373569	0.750913784	0.705833746	0.717686474	0.690428748	0.732929978	0.79645404	812
737	0.841886232	0.843870499	0.683421407	0.682991117	0.686618409	0.641305718	0.794529159	737
178	0.808807616	0.812784342	0.696034772	0.72536323	0.696531984	0.671955577	0.794190288	178
642	0.800807797	0.804787172	0.693965493	0.704510756	0.697049515	0.663646835	0.7924689	642
1009	0.967600308	0.967968883	0.633386321	0.630984761	0.620069755	0.583920818	0.763543014	1009
914	0.925797025	0.927189916	0.645743857	0.645694066	0.637228029	0.604443782	0.753683744	914
993	0.871483811	0.873621107	0.640158484	0.646900014	0.637210118	0.603265224	0.735709384	993
162	0.708902733	0.716908319	0.672159222	0.697361539	0.676784545	0.675402798	0.728732697	162
434	0.836538816	0.840730033	0.649189792	0.67044303	0.640553547	0.629955818	0.727113985	434
898	0.824978404	0.828843402	0.645152848	0.649666062	0.639175841	0.620624707	0.720760593	898
619	0.696794484	0.705230966	0.670081468	0.683860333	0.662704576	0.679253387	0.719158337	619
364	0.7666159	0.772363655	0.660463501	0.682641031	0.636380902	0.645826261	0.704076889	364
534	0.663732347	0.67362399	0.665684949	0.691362916	0.65910328	0.690682181	0.699913826	534
721	0.860338997	0.862080437	0.611477074	0.618610381	0.606492372	0.561524768	0.67653846	721
548	0.686593093	0.695504547	0.651913875	0.670143156	0.633063074	0.661337253	0.674012694	548
875	0.719146129	0.727445669	0.631327253	0.637238023	0.613121109	0.647560548	0.662833725	875
418	0.728112507	0.735699514	0.625523099	0.644017603	0.619842323	0.633832618	0.659288687	418
69	0.402624738	0.425824499	0.337249156	0.365383796	0.293782029	0.40108959	0.20591583	69
769	0.251092486	0.249642465	0.383326916	0.329810737	0.397117581	0.393229071	0.203318911	769
65	0.396765769	0.420360235	0.324154294	0.345332425	0.285259648	0.388163756	0.199946918	65
21	0.198349924	0.199188136	0.393318621	0.382538081	0.402567841	0.410709228	0.198228732	21
229	0.194283034	0.194922723	0.385527725	0.36954587	0.400228295	0.41840663	0.195840334	229
17	0.188868622	0.190049478	0.380664028	0.360896644	0.399402066	0.398895027	0.193543757	17
289	0.164735861	0.165661669	0.368909189	0.333916798	0.382707004	0.409401194	0.185444275	289
1281	0.236404352	0.235521669	0.354388086	0.303318998	0.366575418	0.364744287	0.176820365	1281
5	0.0843789	0.086831682	0.377976267	0.365249609	0.307173522	0.417010389	0.175150254	5
325	0.412109354	0.43475712	0.293306079	0.321289462	0.237835568	0.361409361	0.171770982	325
1	0.07322476	0.075664285	0.365402865	0.345307774	0.382089697	0.403403974	0.169720027	1
321	0.405653018	0.420638389	0.280930325	0.301739662	0.227182339	0.348817033	0.165446374	321
277	0.224195994	0.224611164	0.344098833	0.326915342	0.344236339	0.367264992	0.138978309	277
273	0.214305681	0.214987607	0.330578931	0.302955654	0.33961365	0.355292245	0.154145496	273
261	0.120175878	0.121880774	0.326815431	0.309302059	0.328176901	0.372751722	0.137196322	261
257	0.110481501	0.112211564	0.313147129	0.284014607	0.321895049	0.360211557	0.131938232	257
11281501	0.112211564	0.112211564	0.313147129	0.284014607	0.321895049	0.360211557	0.131938232	11281501

And the Radargram like this:



Technology Frontiers

The inefficiencies of the Multi-Attribute Decision-Making techniques, deterministics, and non-intuitive numerical results may be improved with the use of the Technology Frontiers. Technology Frontiers are defined as the limiting threshold of an “effectiveness” parameter. The technology frontiers are similar to TOPSIS with the use a user-defined function for which maximization is desired. The Technology Frontiers approach involves calculating the parameters for Performance Effectiveness (PE) and Economic Effectiveness (EE) using the baseline values and the value of the metrics for each alternative.

Open the file “Tech Frontiers”. This sheet will graph the technology frontiers for performance and economic effectiveness at each confidence level. This file has many sheets, including “total_data”, “sorted_data_theo”, “sorted_data_10”, “sorted_data_50”, “sorted_data_90”, and “Calc_fronts”, plus sheets for each of the graphs. First, you need to copy the compatible case numbers and 1s and –1s on the “total_data” sheet. Next, copy the value for each response from the “Compatible List” sheet of the “Calc_deterministic_Full_fact_tech” file and paste it into the ‘Theoretical’ column for each response. Now go back to the “Prob_tech_eval” file and click on the first Response sheet. Since the “Tech Frontiers” file needs the response values for the confidence levels of 10%, 50%, and 90%, copy these columns from the response sheet into the appropriate columns on the “total_data” sheet. To clarify’ for the first response, which is TOGW on sheet “R1”, copy columns D, L, and T and paste them into columns O, P, and Q. Repeat this for all the responses. Be sure to modify the number of responses if you have more or less than eight. If your number of cases differs, change cell references as you move through the workbook.

[illegible]

Copy these columns
and paste them here.

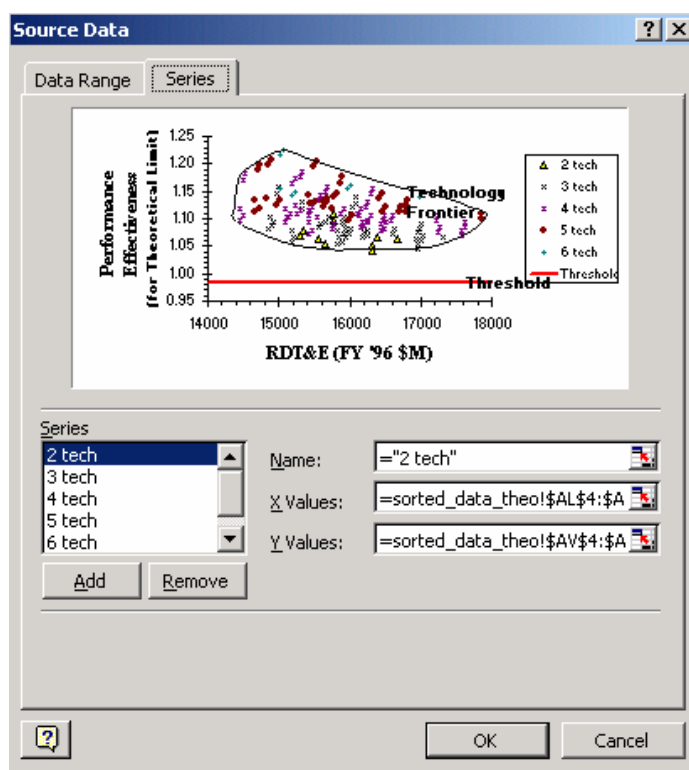
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Now check the 16 graphs that follow. These are plots of RDT&E versus the various effectiveness parameters. These parameters are automatically calculated in the various sheets. If you have different variables or want a different weighing scenario, these formulas must be updated. The basic forms for these equations are:

$$PE_{Alt_i} = \alpha \frac{TOGW_{BL}}{TOGW_{Alt_i}} + \beta \frac{TOFL_{BL}}{TOFL_{Alt_i}} + \chi \frac{Vapp_{BL}}{Vapp_{Alt_i}} + \delta \frac{FON_{BL}}{FON_{Alt_i}} + \varepsilon \frac{SLN_{BL}}{SLN_{Alt_i}}$$

$$EE_{Alt_i} = \alpha \frac{Acq\$_{BL}}{Acq\$_{Alt_i}} + \beta \frac{\$/RPM_{BL}}{\$/RPM_{Alt_i}}$$

The graphs should automatically update based on the new data you copied in and sorted, but you need to change the cell range for each number of technologies. Click on the first graph page, “perf-theo”, right-click and choose ‘Source Data’. On the ‘Series’ tab, click on each of the data series and adjust the x and y values based on the number of technologies.



Now go to the “Calc_fronts” sheet, which calculated the thresholds. To calculate the Performance threshold, use the formula:

$$PE_{threshold} = \alpha \frac{TOGW_{BL}}{1,000,000lbs} + \beta \frac{TOFL_{BL}}{11,000ft} + \chi \frac{Vapp_{BL}}{155kts} + \delta \frac{FON_{BL}}{106EPNLdB} + \varepsilon \frac{SLN_{BL}}{103EPNLdB}$$

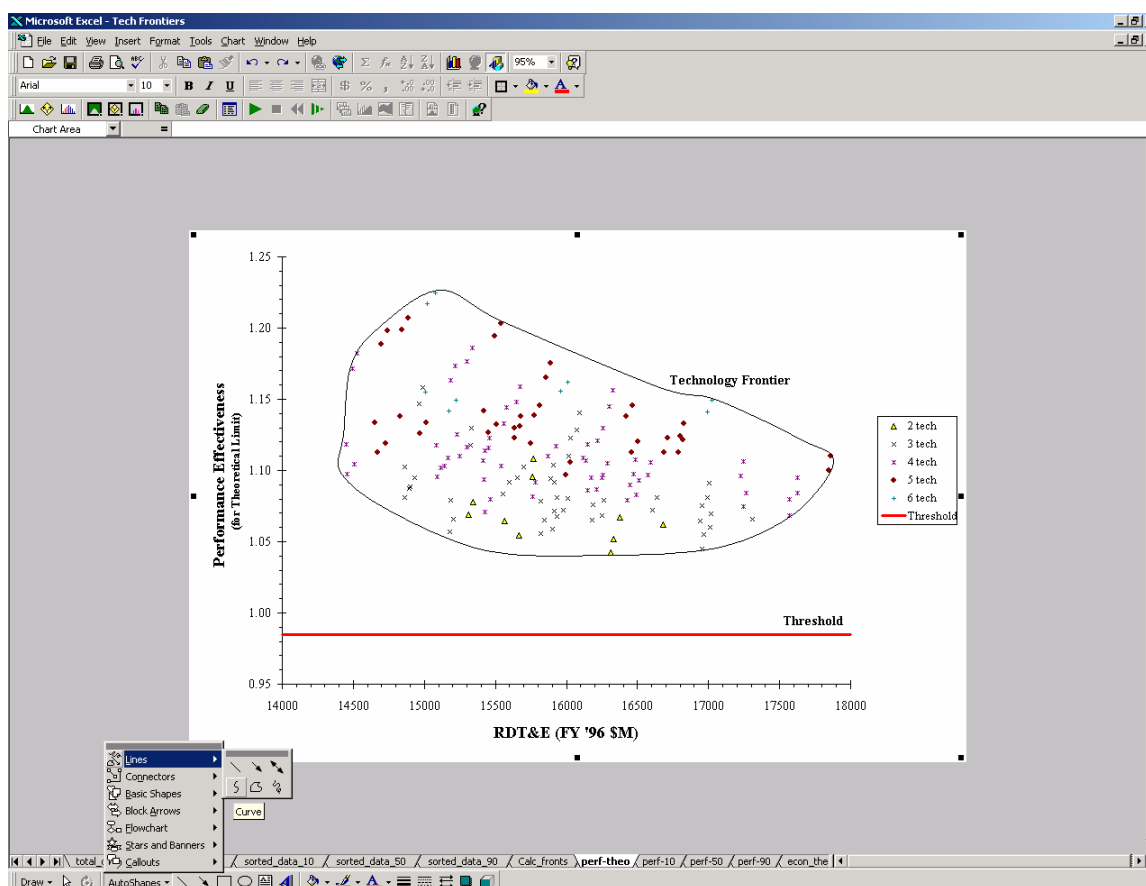
This formula should include all of your performance metrics. If you are using different constraints or metrics, you will need to adjust the formula. The weighing values are arbitrary. For this example, the different metrics have been weighted evenly. The coefficients must sum to one.

For the economic threshold, the formula is:

$$EE_{threshold} = \alpha \frac{Acq\$_{BL}}{\$185M} + \beta \frac{\$/RPM_{BL}}{\$0.10}$$

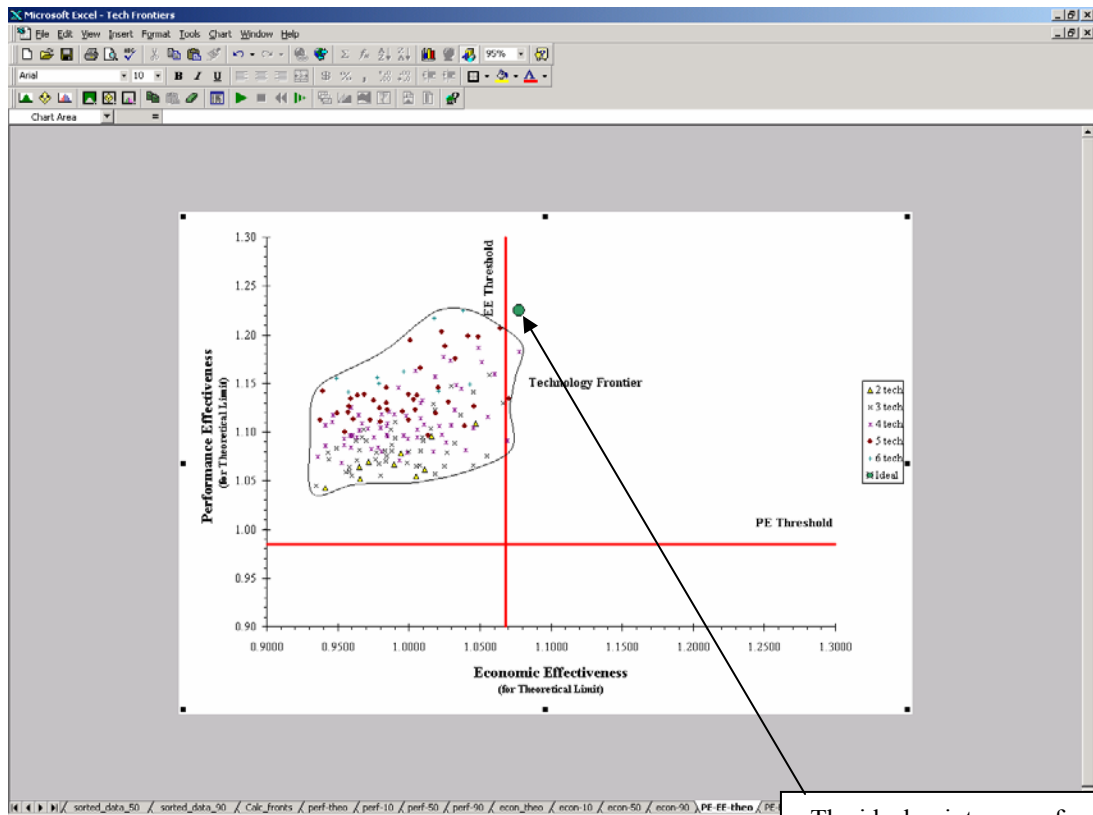
This reflects your economic metrics. If your metrics or constraints vary, the formula must be updated. For this threshold, \$/RPM has been weighted with 0.75 in order to place more importance on that metric. The PE Threshold is the average of the performance and economic thresholds.

The Technology Frontier must be added using drawing tools. You can adjust an existing frontier by right clicking on the shape and selecting **Edit Points**. This will allow you to move and reshape the frontier. To add a new frontier, select **AutoShapes** from the drawing toolbar. Select **Lines** and then the curve as shown below.



You can now drag and click points around the data points to make the technology frontier. Repeat checking that the number of technologies and the technology frontiers are correct on the rest of the graphs.

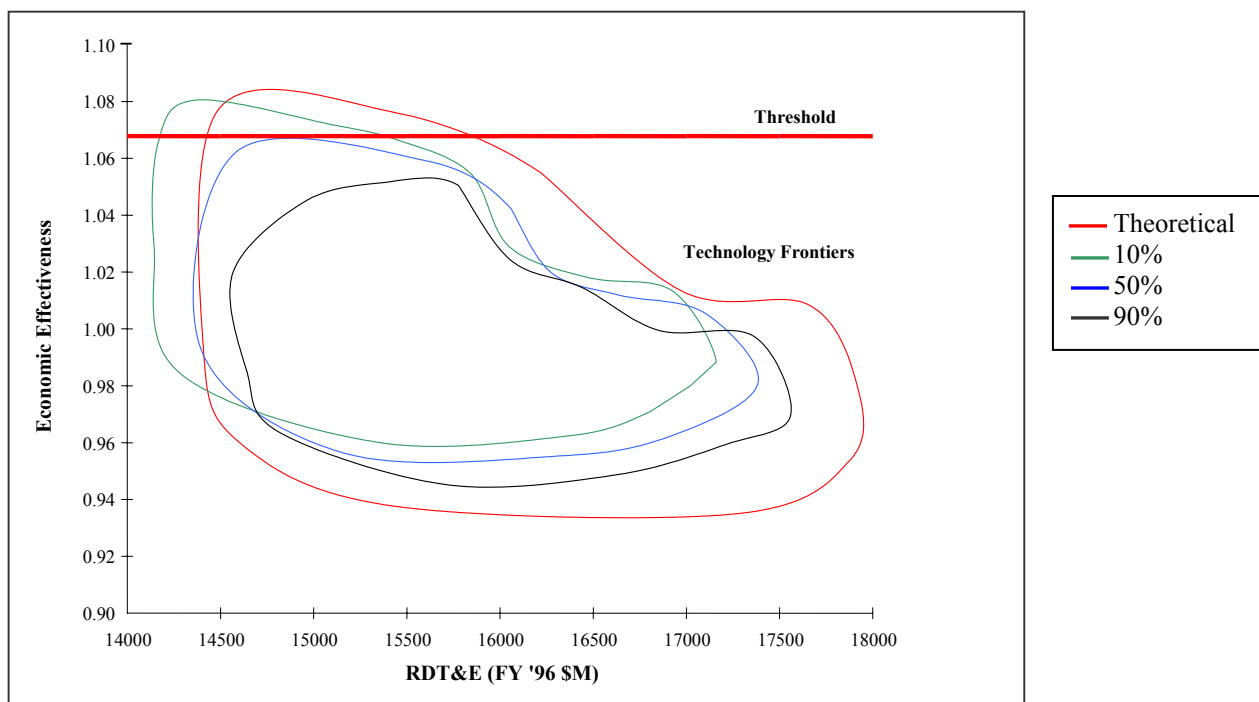
For the graphs of Economic versus Performance Effectiveness, check the data for the ideal point. This point should come from the maximum values of the two data groups at the given confidence level.



The ideal point comes from these two values.

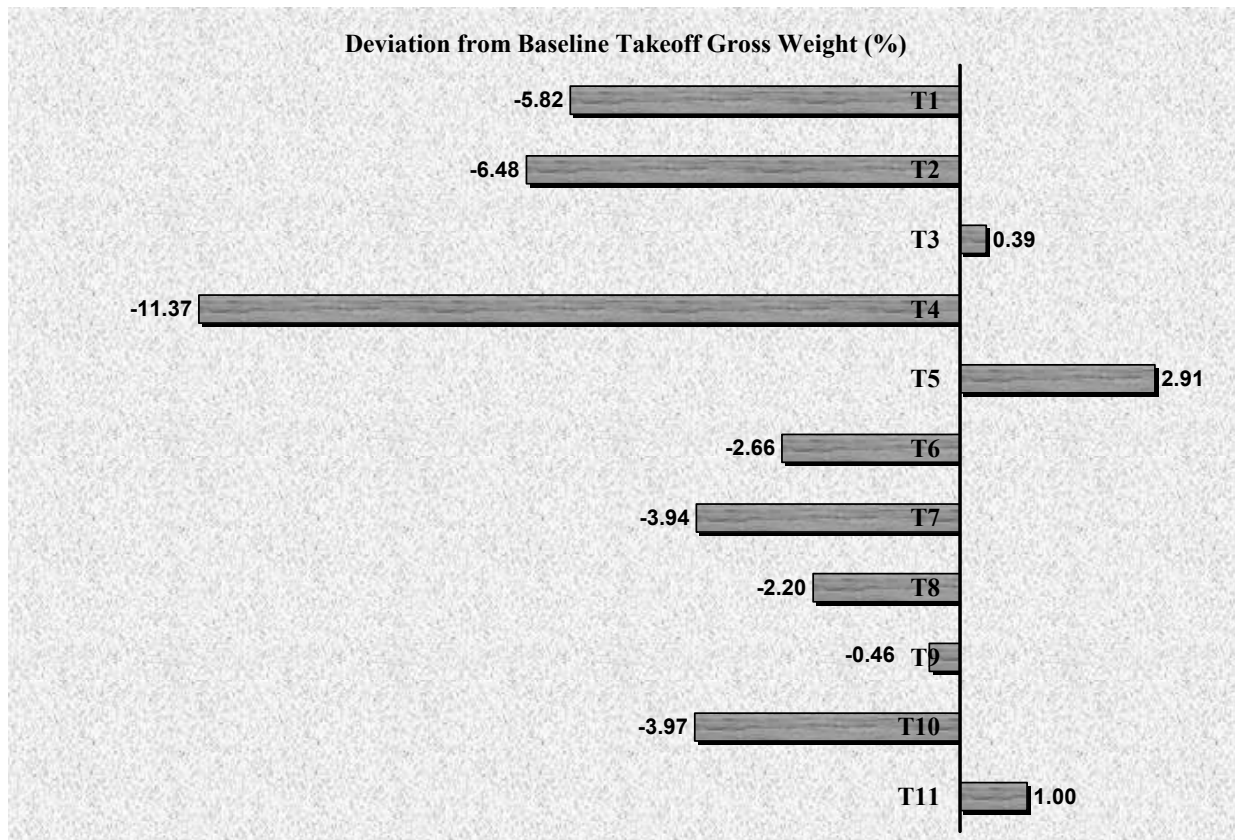
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One interesting comparison is the Technology Frontiers between the confidence levels. This shows how the different confidence levels affect reaching the threshold without changing the general shape of the frontier.



Technology Sensitivities

A technology sensitivity investigation is performed by a comparison of the infusion of the individual technologies to the conventional configuration, and evaluation of the deviations in metric values. The idea here is to determine which of the different technologies, as applied in isolation of the others, most influences the vehicle metrics. You have all the data and can simply manipulate it and format some pretty pictures. The example below is the impact of the 11 individual technologies on the TOGW of an HSCT. As you can see, T4, which was the HLFC technology, had the most significant impact on reducing the TOGW from the baseline value. Whereas T5, which was the Environmental Engines technology, had the most significant NEGATIVE impact on the TOGW.



Now open the file “Tech Sensitivities”. This file will calculate and graph the technology sensitivities. The first page is the “Data” page, where you need to copy in the technology impact matrix into the graph starting in cell B4. Then update the formulas for the “k” factors in the second graph starting in cell B18. Change the baseline in cells B45 to I45 if it differs from the one given. Be sure to edit the number of columns and rows if you have more or less technologies, metrics, or “k” factors. Next, you need to update the “RSE” page for your RSE. Then go back to the “Data” page and select the **Tools** menu, then **Macro** and then **Macros**. Choose the “run_techs” macro and edit it to reflect the number of technologies and responses. Make sure the cell references are right. Now run the macro. The cells from B32 to I42 should fill in with the metric values, and the ‘Percent Change from Original Baseline’ table should automatically update. Once the macro has finished, you can edit the graphs for the metrics.

This information can also be found from the “Calc_deterministic_Full_fact_tech” spreadsheet. Find the case that has only the tech you are interested in on. Copy the metrics from these cases into the ‘Metrics’ matrix. This will update the ‘Percent Change from Baseline’ and the graphs.

Microsoft Excel - Tech Sensitivities.xls

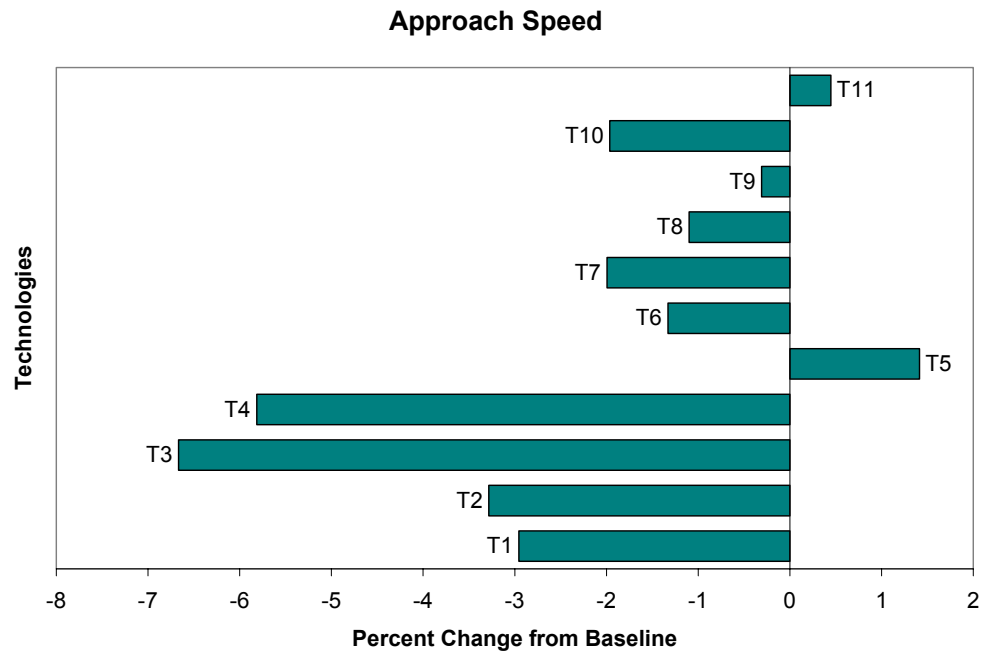
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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
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Ready

Here's a sample technology sensitivity graph of approach speed. You can see that T5, environmental engines, increased the baseline the most, while T3, which is circulation control, reduced it the most.



Using the “Prob_tech eval” sheet, it is possible to graph the different confidence levels for each technology sensitivity. Open the file and save it as “Prob_each tech”. Now change the tech combinations on the “Cases” sheet so that each row has one tech on and the rest off. This chart should have as many rows as you have technologies.

Microsoft Excel - Prob_each.tech.xls

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Now, change the number of cases on the “Definitions” sheet and rerun the **Monte_Carlo** macro.

Open the “Tech Sensitivities-prob” file. Copy the data from each response page into the probabilistic evaluation section.

Microsoft Excel

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T2 = 818637.889768802

Prob_each tech.xls

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Case	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%
2	T1	807,477.85	810,139.66	810,306.99	811,094.74	811,783.18	812,084.64	812,668.03	812,879.42	813,199.00	813,866.15	814,746.46	814,958.78	815,386.83	816,204.42	816,522.04	817,143.61	817,578.60	818,175.21	818,637.89
3	T2	802,357.30	805,057.20	806,126.39	807,676.98	808,434.67	808,943.18	809,553.25	810,066.37	810,376.16	810,765.27	811,037.51	811,898.55	812,142.61	813,303.71	814,329.54	815,542.32	816,296.11	816,794.67	817,897.39
4	T3	856,846.97	857,440.48	857,526.67	857,630.94	857,687.76	857,724.30	857,763.34	857,830.35	857,885.44	857,953.91	857,996.28	858,043.67	858,085.12	858,131.05	858,159.15	858,185.85	858,312.55	858,350.15	858,433.09
5	T4	755,941.80	760,646.97	764,735.83	767,258.73	768,376.57	769,917.80	771,758.70	772,487.66	774,831.99	776,019.30	776,628.91	777,764.04	779,103.75	779,957.66	781,517.43	783,603.62	784,746.77	788,382.46	791,100.50
6	T5	862,146.20	866,869.34	869,360.66	870,868.06	871,517.42	872,627.62	873,286.93	873,730.94	873,985.57	874,475.41	875,334.28	875,975.58	877,159.99	877,603.17	878,340.75	878,757.59	879,402.93	879,871.58	880,377.69
7	T6	833,026.62	833,620.54	833,735.76	834,119.10	834,600.07	834,761.70	835,120.45	835,641.01	835,790.24	836,087.08	836,344.75	836,570.82	836,887.96	837,363.69	838,017.42	838,478.97	838,941.99	839,282.55	840,306.39
8	T7	823,758.38	824,648.07	825,124.24	825,711.74	826,086.39	826,654.66	826,930.86	827,323.30	827,705.28	828,071.91	828,385.17	828,849.13	829,271.94	829,417.36	829,868.45	830,260.34	831,028.54	831,520.71	832,064.39
9	T8	837,083.62	837,482.52	837,676.76	838,036.89	838,401.84	838,649.53	838,698.38	838,934.36	839,072.61	839,468.68	839,754.44	840,007.73	840,137.44	840,239.38	840,426.43	840,884.46	841,175.72	841,426.99	842,004.88
10	T9	849,325.55	849,649.62	849,963.92	850,282.57	850,518.79	850,773.97	850,866.96	851,044.08	851,137.86	851,298.44	851,420.49	851,569.60	851,730.06	851,918.47	852,283.33	852,382.64	852,545.40	853,053.60	853,425.00
11	T10	818,481.40	819,898.78	820,626.59	822,051.27	823,445.48	823,563.15	824,069.24	824,565.88	825,013.11	825,630.52	826,009.60	826,779.86	827,672.43	828,029.89	828,859.57	829,833.72	830,351.37	831,477.12	832,153.49
12	T11	860,787.73	861,176.99	861,445.59	861,508.03	861,645.83	861,787.63	861,756.22	861,880.58	861,976.57	862,005.27	862,125.97	862,204.46	862,275.22	862,311.13	862,360.36	862,401.19	862,511.16	862,715.86	862,800.18

Copy these to here.

Tech Sensitivities-prob.xls

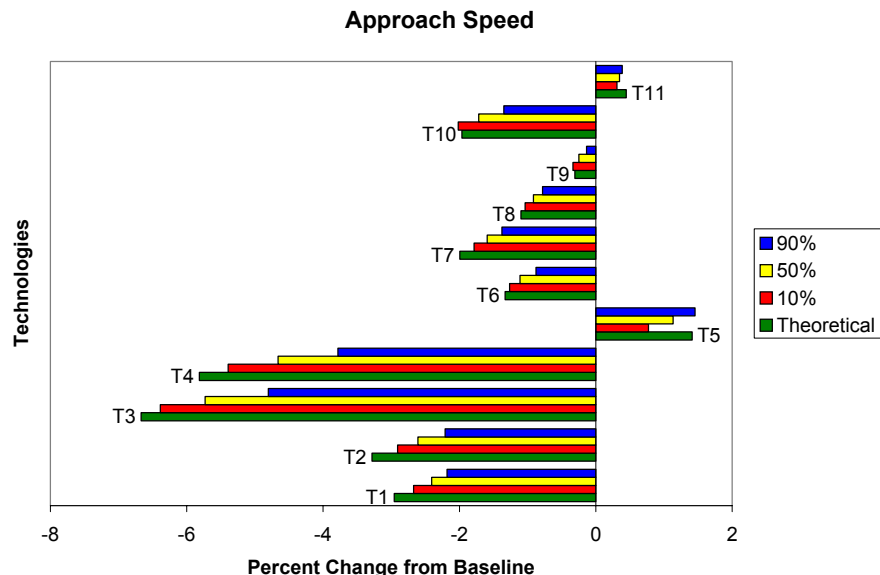
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
59																							
60	Data for Confidence Levels-Probabilities																						
61		TOGW	TOFL	Vapp	FlyOver	Sideline	Acq \$	RD&E	\$/RPM														
62		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	
63	T1																						
64	T2																						
65	T3																						
66	T4																						
67	T5																						
68	T6																						
69	T7																						
70	T8																						
71	T9																						
72	T10																						
73	T11																						
74																							
75	Percent Change																						
76		TOGW	TOFL	Vapp	FlyOver	Sideline	Acq \$	RD&E	\$/RPM														
77		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%		
78	T1	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		
79	T2	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		
80	T3	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		
81	T4	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		
82	T5	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		
83	T6	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		
84	T7	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		
85	T8	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		
86	T9	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		
87	T10	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		
88	T11	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		

Ready

Sum=27,546,312.16

NUM

The percent change and the graphs will automatically update for the new data. Here is what the graph for Approach Speed looks like now with the confidence levels:



Genetic Algorithms

Genetic Algorithms (GA) offer a unique way of selecting the best technology combination by simulating the natural processes of breeding and competition. Random combinations of technologies are created with an array of 1's and 0's representing the techs in the on and off configurations respectively. Each combination representing all the technologies in either the on or off position is called a chromosome. A certain number of chromosomes are randomly created within a population and then the RSE's are used to obtain the response for each combination. The responses are normalized by some kind of "fitness function" which allows one number to represent the goodness of the combination. A combination with a low fitness value is closer to the ideal since the minimization of the metrics is desirable. The population is then put through a reproduction scheme whereby the more "fit" a combination, the better the chance that it will be selected for reproduction and its offspring will become more dominant in the next generation. In addition to competition and reproduction, the concept of mutation is introduced into a population in order to capture effects that might not have been available in the first random selection. Thus after several generations the most fit combinations will have achieved prominence and the "best" combination can be found.

When a large number of technologies exist the only way to use JMP and the TOPSIS method is to break the techs down into groups of 13 or less and analyze them separately. This, however, does not capture all the interactions between technologies. The best use of genetic algorithms comes when the number of available technologies is greater than 13, which is the largest full factorial combination that JMP can create. GA is run through a Matlab code that is very modular and must be set up for each concept that is investigated. This is done by creating certain text files that contain the information needed by the program.

An example GA run for a 225 passenger subsonic passenger jet is shown here. The background information for this jet is found in the "225 Pax Info" Excel file. This concept has 36 possible technologies for infusion, which would require three separate groups under TOPSIS. Here we will analyze them all together using GA's. The first and most complicated task is to determine patterns within the technology compatibilities. Because each combination is compared to the others within each population and the next generation based on this result, it is imperative that only compatible combinations be used in competition.

Table 8: Technology Compatibility Matrix

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30	T31	T32	T33	T34	T35	T36	
T1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T2			1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T3				1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0	1	
T4					1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T5						1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0	
T6							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T7								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T8									1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	0	1	
T9										1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	0		
T10											1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
T11												1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T12													1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T13														1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	0	1	1	
T14															1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T15																1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	0			
T16																	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	
T17																		1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T18																			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T19																				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T20																					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T21																						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T22																							1	1	1	1	1	1	1	1	1	1	1	1	1	1	
T23																								1	1	1	1	1	1	1	1	1	1	1	1	1	
T24																									1	1	1	1	1	1	1	1	1	1	1	1	1
T25																										1	1	1	1	1	1	1	1	1	1	1	1
T26																											1	1	1	1	1	1	1	1	1	1	1
T27																												1	1	1	1	1	1	1	1	1	1
T28																													1	1	1	1	1	1	1	1	1
T29																														1	1	1	1	1	1	1	1
T30																															1	1	1	1	1	1	1
T31																																1	1	1	1	1	1
T32																																	1	0	1	1	1
T33																																					

By further analyzing this compatibility matrix, it would become evident that all the incompatible combinations fall within groups of technologies that are compatible with any technology outside the group but incompatible with anything in the group. These groups are shown in Table 9. The 12 remaining technologies are compatible with all other technologies under consideration.

Table 9: Technology Groups

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
T3	T5	T21	T2	T16	T4
T8	T9	T31	T12	T19	T14
T13	T15	T34	T17	T25	T18
T23	T24				
T32	T33				
T35	T36				

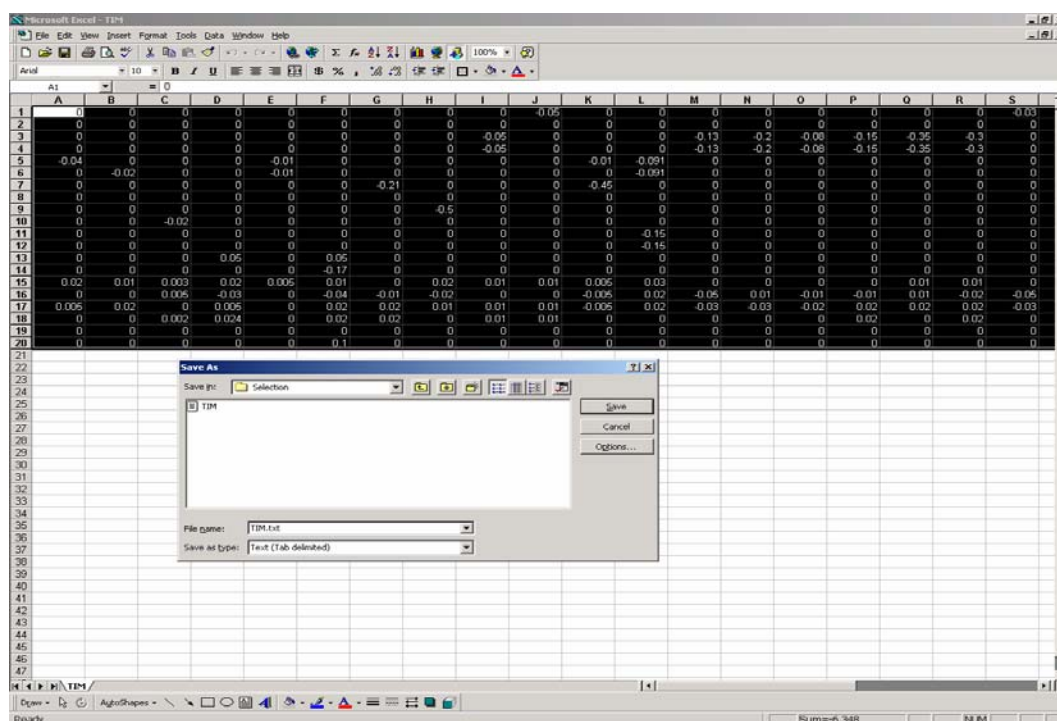
The original organization of the TIM had nothing to do with which techs were in which compatibility group but the Matlab requires that the chromosomes created for it be organized by these groups. Therefore, it is necessary to rearrange the values in the TIM. The order needed is given below.

Technologies Compatible with Everything												Group 1					Group 2					Group 3			Group 4			Group 5			Group 6				
1	6	7	10	11	20	22	26	27	28	29	30	3	8	13	23	32	35	5	9	15	24	33	36	21	31	34	2	12	17	16	19	25	4	14	18

Open the Technology Impact Matrix and rearrange the technologies in order. Be sure to put in zeros where the technology does not have an effect. Copy just the impacts and paste them as values into a new Excel sheet.

The screenshot displays the Microsoft Excel interface with the 'TIM for GA TIES' spreadsheet. The columns are labeled A through AK, and the rows are numbered 1 through 24. The data is organized by technology groups as defined in Table 9. A context menu is open over the data area, showing options like Cut, Copy, Paste, and Paste Special. The status bar at the bottom shows 'Sum=6.348' and 'NUM'.

Save this file as the TAB delimited text, named "TIM.txt" as shown below.



Now create the other input files. Copy the RSE's from JMP into EXCEL, then remove the titles in the first column by removing column A. Save the file as TAB delimited text under the file name "RSE.txt". The RSE's need the inputs to be in the same form as FLOPS so the "k" factors must be converted in order to be useful. The converting factors and multipliers can be found in Table 10. Most of the values needed are factors distributed around 1, where an increase in the value leads to a number greater than 1 and a decrease leads to a value less than 1. Some of the economic factors, however, are based around 0. Other variables are needed as dimensional values and not factors (it will depend on which variables you are using, check the FLOPS manual for more information). The Matlab program will convert the "k" factors given the factors and multipliers in Table 10. You should copy and save the numbers in this table as TAB delimited with the filename "ranges.txt".

Table 10: K Factors and Baseline

	Minimum k	Maximum k	Factor	Baseline Multiplier
Wing Weight	0.65	1.15	1	1
Fuselage Weight	0.75	1	1	1
HT Weight	0.6	1	1	1
VT Weight	0.6	1	1	1
Cdi	0.8	1	1	1
Cdo	0.8	1	1	1
LG Weight	0.75	1	1	1
Avionics Weight	0.5	1.05	1	1
Hydraulics Weight	0.5	1.05	1	1
Furn. and Equip. Weight	0.9	1.05	1	1
VT Area	1	1.8	1	250
HT Area	1	1.88888889	1	450
Engine Weight	0.55	1.05	1	12126
Fuel Consumption	0.8	1.01	1	1
RDT&E Costs	-0.2	0.2	0	1
O&S Costs	-0.2	0.2	0	1
Production Costs	-0.2	0.2	0	1
Utilization	0.8	1.2	1	4915
Wing Area	0.82111437	1.026392962	1	3410
Thrust-to-weight ratio	1	1.166666667	1	0.3

In order for the chromosomes to be compared, there must be a number that represents the fitness of each. This number can be chosen from a variety of possibilities based on what metrics are of greatest interest in that case. For this example a comparison between several metrics and their constraint values will be used as the measurement. The equation for the fitness factor is:

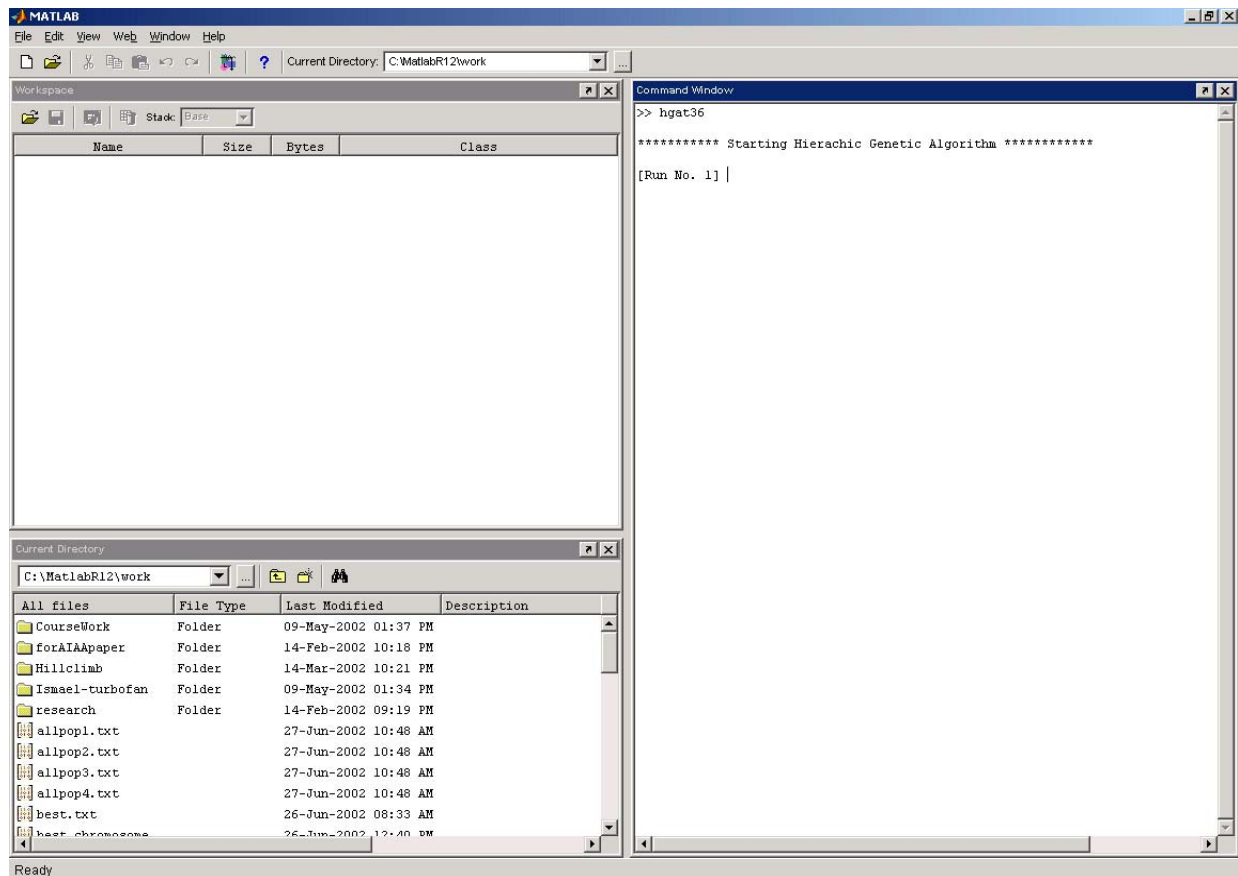
$$F = \alpha \frac{\text{response}_1}{\text{constraint}_1} + \beta \frac{\text{response}_2}{\text{constraint}_2} + \dots$$

where alpha is the first weighting value, beta is the second weighting value, and so on. The constraints are stored in the order of this equation in a text file called “base.txt” with the weighting values for the metric located in the row beneath them. In this example, there are five metrics with constraints that are significant, which are CO₂, \$/RPM, TAROC, DOC+I, and NO_x. These constraints and weighting values can be entered into two lines of EXCEL and saved as TAB delimited text. The Genetic Algorithm programs are set up so that minimization is desirable. If you wish to maximize your responses, it is necessary to modify the “run225.m” file. To do this, add the following line of code after the last existing line:

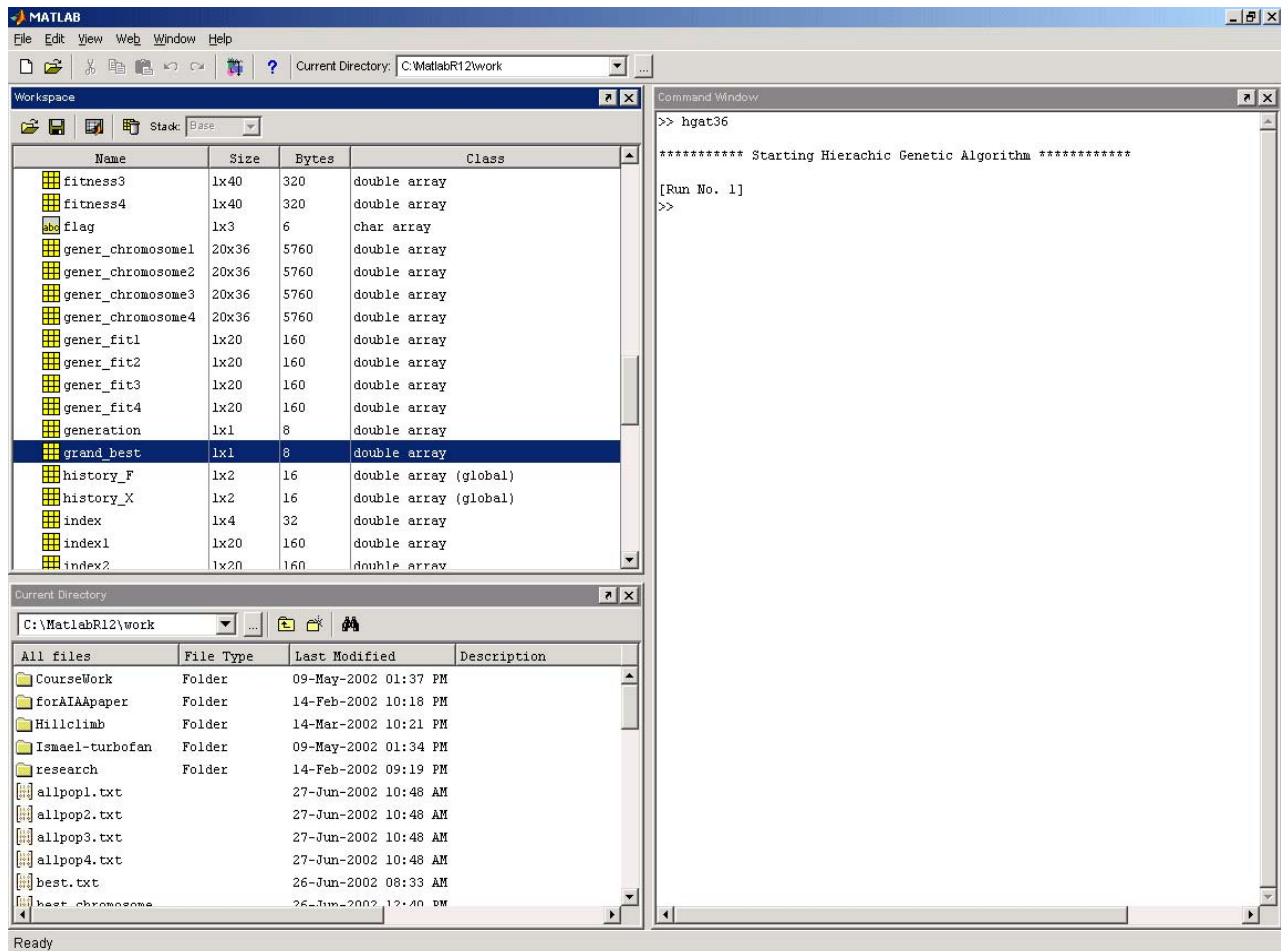
$$F_value = 1 / F_value$$

This is required because the “tournament.m” file is set up so that a smaller fitness value is preferable.

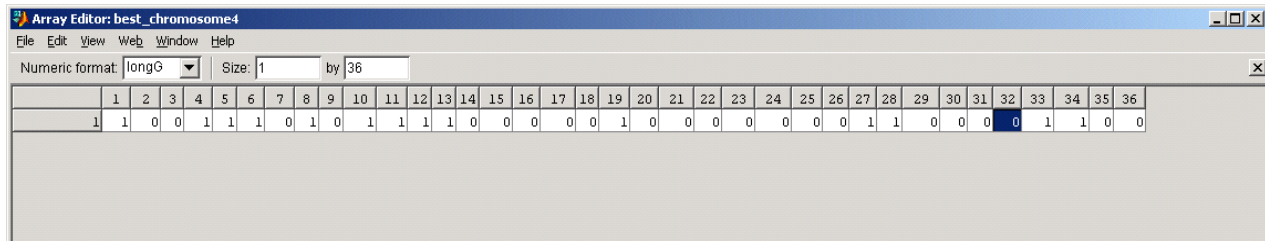
The Genetic Algorithm code is not a single program; instead it consists of 21 separate program files. These should all be in one folder called “Matlab Files”. This folder should also contain the various input files you created above. It is essential to set up Matlab to recognize wherever you have the program and input files. To do this open the **File** menu, go to **Set Path** then **Add Folder** and add the “Matlab Files” folder where the files are located. Once all the input files are correctly set up all that’s left is to run the code. Make sure that there are no files in your work directory that duplicate the names used for this program. If there are, these files will be used instead of the correct ones. If you plan on running a different number of runs, be sure to change the “hgate36.m” file by changing the ‘RUNS’ line in the ‘Input’ section. To run the Genetic Algorithms codes, type ‘hgate36’ in the Matlab command window. The entire Genetic Algorithm process will run from this code.



Once the program is finished running for the number of runs selected, it is just a simple matter to analyze the output and determine the best chromosome. Open the 'grand_best' variable in the Matlab Workspace window.



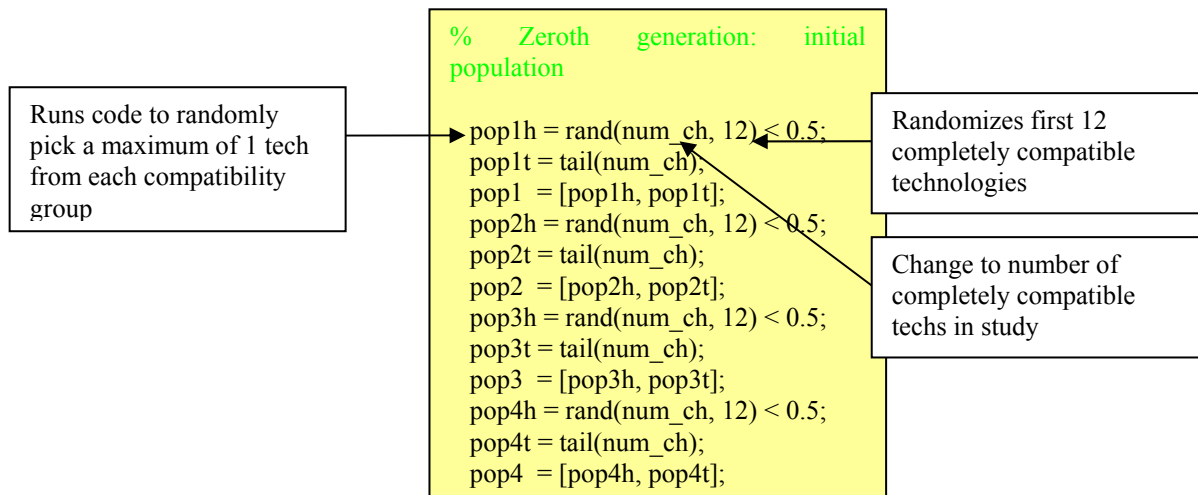
The number that this gives you represents the best fitness that any technology combination was able to obtain. Since there were four populations run simultaneously, it is necessary to determine from which of these populations this fitness value comes from. This can be done by opening the 'best_fit' variables and determining which matches the best overall value. Then open the 'best_chromosome' that corresponds to the best fit; this is your best technology combination. Note that the order of the "on" and "off" tech switches corresponds to that of the Technology Impact Matrix.



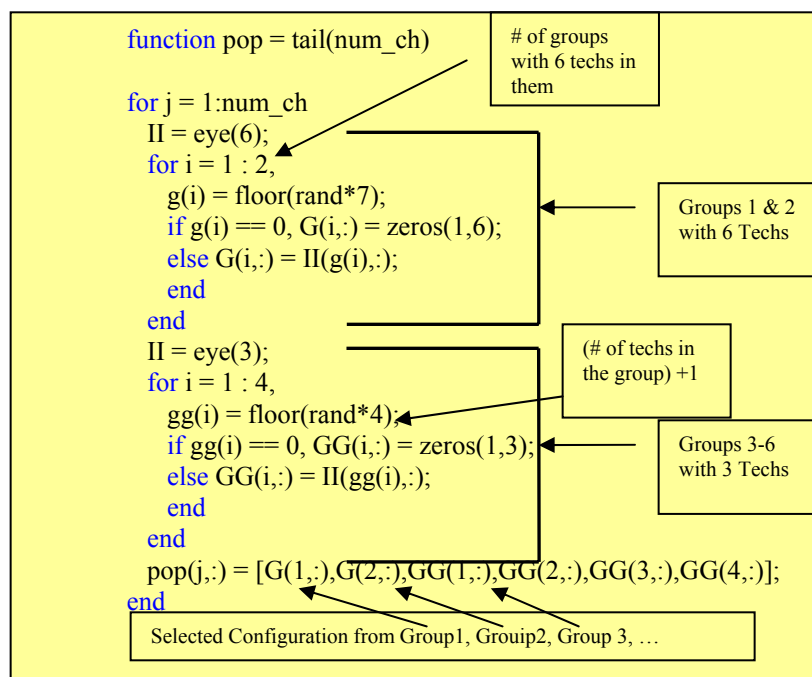
Modifying the Code

For a different vehicle and technologies this code must be significantly changed in order to be used. The most difficult aspect will be setting the code to only pick compatible cases. If your vehicle has technologies that can be organized into groups such as in the previous example where $A \neq B$, $A \neq C$, and $B \neq C$ then the changes to the code are minimal. However, for technology sets where $A \neq B$, $A \neq C$, but $B = C$ then a whole new approach must be sought.

For the former case where the groups are different but still all the techs can be categorized into one then the procedure is rather straightforward. First let's look at the initial random population selection. Open the file "hgate36.m" and scroll down to lines 69-82.

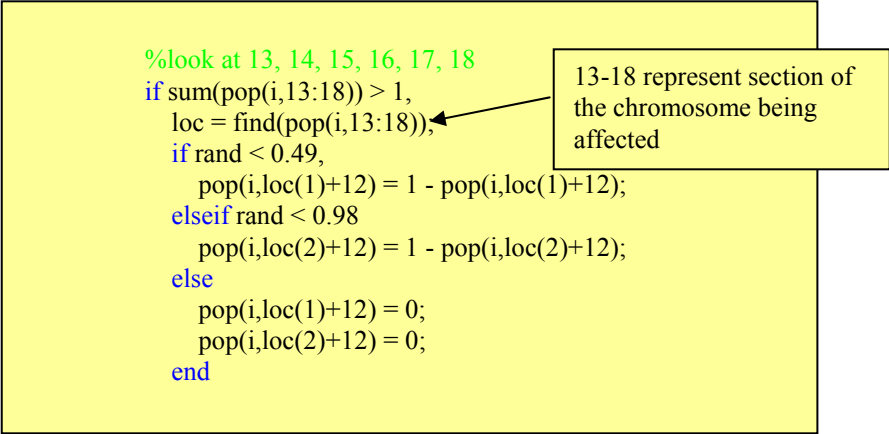


In this area of the code change the 12 to the number of completely compatible technologies in your study. It will also have to be changed in lines 87, 181, and 234. In order to modify the code for the selection of techs in each group open the file "tail.m"



The first thing that is evident is that there are only 2 calculations going on. This is due to our previous example having only 2 different sized groups- groups 1&2 with 6 techs each and groups 3-6 with 3 techs each. If your case has more variance in the size of the groups you will need to create new nested 'for' loops. The overall method of this code is blatantly simple: an identity matrix is formed with each row representing a case with only 1 of the technologies turned on. There is an equal probability for any of these rows to be selected along with the same probability that none will be selected which represents the case of no technologies from that group being activated. In order to modify the code the 'for' loops must be changed to represent the number of techs in each group. At the end of the file the selected configurations are combined to form the last section of the chromosome. This must be changed as well to correctly piece together the selections in your new technology set.

This takes care of the initial population creation but the later mutation of the chromosome must also be altered. Mutation is taken into account in order to possibly allow in technologies not selected in the initial population. The mutation code can, however, allow in technologies that are incompatible with those already selected. For this possibility another code is run in order to screen for this effect. Open the file "genemanipulation.m" and look at lines 5-16.



```
%look at 13, 14, 15, 16, 17, 18
if sum(pop(i,13:18)) > 1,
    loc = find(pop(i,13:18));
    if rand < 0.49,
        pop(i,loc(1)+12) = 1 - pop(i,loc(1)+12);
    elseif rand < 0.98
        pop(i,loc(2)+12) = 1 - pop(i,loc(2)+12);
    else
        pop(i,loc(1)+12) = 0;
        pop(i,loc(2)+12) = 0;
    end
end
```

13-18 represent section of the chromosome being affected

This section of the code looks through the part of the chromosome containing group 1 and determines if more than 1 of the technologies in the group is on and, if so, there is a 49% chance of the first tech being selected, a 49% of the second tech being selected and a 2% chance of both being turned off. This is run through several times for each group to ensure that if more than only 1 tech and most remains on. In your code you must edit these sections of the code in order to look at each section of the chromosome representing incompatible technologies and make a proper selection. Now that the chromosomes are correctly set up the rest of the code will run without needing any changes.

There are a few things that can be changed should you choose to do so such as the equation for fitness used by the algorithm to compare the chromosome in competition. This can be done in the file "run225.m" on line 44. This equation is simple to edit but you must remember that it and the file "base.txt" are linked so changes to one necessitate changes to the other. Changing the RSE's and TIM's can be done just as described in the previous 225 passenger example.

If you have any questions or comments, you can reach Dr. Kirby at
michelle.kirby@aerospace.gatech.edu.

UNDER CONSTRUCTION

Appendix A: Parse Shell Script Description

```
#####
#
#                                     PARSE                                     #
#
#           Written by Samir El Aichaoui
#       Supervised by Dr. Mark A. Hale
#       Aerospace System Design Lab
#       Georgia Institute of Technology
#           Summer 1998
#
#####

#####
# DESCRIPTION
#
# PARSE allows a user to extract data from a formatted data file. We have found it to be
# particularly useful for use with automating analysis, "wrapping", programs for use in
# software architectures.
#
# PARSE is command line driven and uses tk/tcl as its core.
#
#####

#####
# ARGUMENTS
#
# This program supports the following command-line options :
#   -search      allow you to define the search criteria that will define a certain position
#                 (or more specifically line) in the file. this option requires a string
#                 as an argument. This search string need to be present in the file
#                 This option is required.
#   -read        specifies which word from the line you want to extract. When this option
#                 is not specified the default 1 is used.
#   -forward     start the search for the search criteria from the beginning of the file.
#   -back        start the search for the search criteria from the end of the file, this is
#                 useful when the results sought are at the end of the output file. The
#                 default value is -forward.
#   -occurance   defines the number of times the search criteria occur in the file before
#                 reaching the line considered. the default value is equal to 1.
#   -offset      defines the number of lines offset with respect to the line defined by the
#                 search string. the default value is equal to zero.
#   -split string1 after string2 is used in the case of values following string2
#                 ( example = ) and separated by string1 ( example , ).
#   -matrix int1 int2 allows to extract a matrix instead of a single string. int1 defines
#                 the number of rows and int2 specifies the number of columns.
#
#####
```

```
#####
#      USAGE      #
#      usage:  parse98 -search string [-read int] [-forward|-back] [-split char after char ] #
#              [-matrix int int ] [-occurance int] [-offset int] [-help] file #
#####
#      EXAMPLES   #
#      #          #
# 1)      parse98 -search "something" input.dat #
#              will search for the first occurrence, first word in the line, #
#              from the beginning #
#              of the file input.dat for the word "something" #
#              the value returned will be the first value on the line #
#      #          #
# 2)      parse98 -search "something" -back input.dat #
#              will search for the first occurrence, first word in the line, #
#              from the end of the file input.dat for the word "something" #
#              the value returned will be the first value on the line #
#      #          #
# 3)      parse98 -search "something" -read 3 -matrix 3 3 -back -offset -2 -occurance 3 \ #
#              input.dat will look for the matrix found two lines before the #
#              line containing "something" in its third occurrence in the file. #
#              The matrix will have three rows and three columns and will be #
#              starting in each line at the third word. The file used is #
#              input.dat. #
#      #          #
# 4)      parse98 -search "something" -read 3 -split "after =" input.dat #
#              if the line found is "something=3.4,5.6,7.6" #
#              then the result returned is 5.6 #
#      #          #
#####
```

Appendix B: TSW Program Guide

Aerospace Systems Design Laboratory
 School of Aerospace Engineering
 Atlanta, GA 30332-0150
 www.asdl.gatech.edu

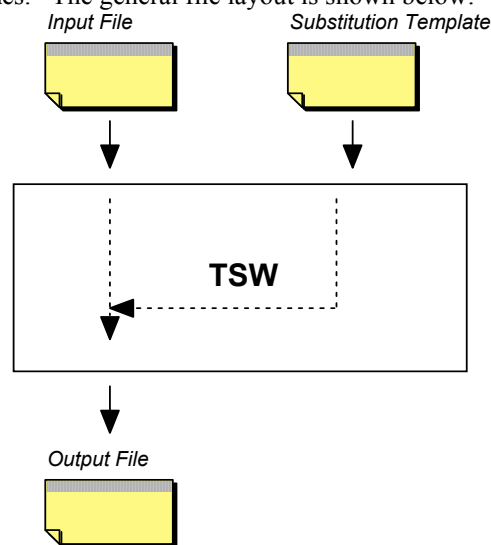
March 12, 2001

Background

TSW is a UNIX utility program that substitutes variable values into a namelist formatted input file.

Files

There are three main files of interest when using TSW for file substitution. The files can have any name but all three files must have unique file names. The general file layout is shown below:



Input File

The input file must be namelist formatted input file in which variable values are to be substituted. A sample input file follows:

```

$OPTION
  IOPT=1, IFITE=1,
  IANAL=3,
$END
$CONFIN
  DESRNG=800.0, TWR=0.63,
  GW=30000.0,0.0,25000.0,35000.0,
$END
  
```

The following rules apply:

- Namelists must be all \$ or all & separated
- Variables may be scalar or array
- Tabs may not be used in the file (e.g. at the beginning of the line)
- Variables must be comma separated and the last variable in a namelist must have a comma after it

Substitution Template

The *Substitution Template* defines what variables are to be substituted into the namelist and what the new values are. The general file format is:

```

namelist variable value
  
```



```
namelist variable value
...
```

The following rules apply:

- All variable and namelist names must appear exactly as they are in the input file
- If a scalar variable does not appear in the given namelist, it is appended automatically to the end. Array variables cannot be appended.
- Array variable values are indicated by []. For example, the third element of the variable GW is indicated by GW[3].
- A "*" can be used to apply the substitution to all namelists.

A sample substitution template follows:

```
OPTION IFITE 2
OPTION IENG 1
CONFIN DESRNG 750.0
CONFIN GW[3] 28000.0
```

Output File

The output from the file parsing is put into the output file.

The following rules apply:

- The output filename cannot be the same name as the input filename
- The file is organized for single variables to appear on their own line
- Formatted text is ignored

A sample output file follows for the examples given above:

```
$OPTION
  IOPT=1,
  IFITE=2,
  IANAL=3,
  IENG=1,
$END
$CONFIN
  DESRNG=750.0,
  TWR=0.63,
  GW=30000.0,0.0,28000.0,35000.0,
$END
```

Execution

TSW is executed from the UNIX command prompt. The syntax is:

```
tsw -input InputFilename -output OutputFilename SubstitutionFile
```

The following rules apply:

- The input file must exist
- The substitution template file must exist
- The input and output file must not have the same name